J C Branner

MEMOIRS OF THE GEOLOGICAL SURVEY

ENGLAND AND WALES.

THE COALS OF SOUTH WALES

WITH SPECIAL REFERENCE TO

THE ORIGIN AND DISTRIBUTION OF ANTHRACITE.

BY AUBREY STRAHAN, M.A., Sc.D., F.R.S., F.G.S., AND

W. POLLARD, M.A., D.Sc., F.G.S.

ASSISTED BY E. G. RADLEY.

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PREFACE.

PREPARATIONS for this Memoir on the Coals ot South Wales were commenced in 1901, when Sir Archibald Geikie was Director-General of the Geological Survey, and the collection of material has proceeded since that date, as circumstances allowed. Though obviously incomplete, in the sense that analyses might be multiplied indefinitely, the work had so far progressed in 1907 as to lead to a more or less definite opinion as to the relative distribution of anthracitic and bituminous coals, and as to the origin of the difference between them. The time appeared, therefore, to have arrived for publication of the results, though admittedly a larger number of analyses would add precision to the generalisations, and illustrate more fully certain seams and certain parts of the coalfield.

Necessarily there was much doubt at its inception what form the investigation should take. That each seam should be examined separately, and its modifications traced step by step from the bituminous into the anthracitic region, was clear. It was desirable also that all analyses should be made on a uniform system. For various reasons, explained in the following pages, it was impossible to follow fully so ideal a scheme. Samples of coal were not always procurable from the desired seam or locality, while a large number of analyses, the accuracy of which there was no reason to doubt, would have been inadmissible. Eventually it was decided that while special attention was being devoted to certain seams, opportunities ought not to be lost of getting specimens of others which happened to be accessible.

Difficulty arose also from the natural reluctance of the colliery proprietors to consent to the publication of coal-analyses over which they had had no control. This was overcome by the assistance kindly rendered by the South Wales Institute of Engineers. Not only was an arrangement made with the proprietors under which specimens could be collected and analyses published, but through Mr. Jones Price, Secretary to the Institute, we were kept informed where specimens could be procured.

This volume, which is the outcome of the investigation, has been written by Dr. Strahan and Dr. Pollard. The latter, with

the assistance of Mr. E. G. Radley, has carried out all the chemical work, except some analyses which were made for the Geological Survey by Mr. C. A. Seyler. To Dr. Pollard also are due the chapters dealing with the methods of analysis, possible causes of error in analysis, and the classification of coals. The relation of carbon to hydrogen having proved to be the most reliable factor for expressing the character of the coal as regards anthracitism, the series of maps (forming Plates 3–7) were prepared to illustrate the distribution of anthracite on this basis. So far as we are aware, this is the first attempt to define the distribution of anthracite on purely experimental data.

Our thanks are due to Mr. Seyler for much assistance. He has not only furnished us with a large number of analyses, made independently of this investigation, but has given advice of great value in deciding on the method of analysis. We have also had the benefit of his comments on this volume during its passage through the press.

J. J. H. TEALL,
Director.

Geological Survey Office,
28, *Jermyn Street, London,*
17th February, 1908.

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THE COALS OF SOUTH WALES

WITH SPECIAL REFERENCE TO

THE ORIGIN AND DISTRIBUTION OF ANTHRACITE.

CHAPTER I.

HISTORICAL AND INTRODUCTORY.

By A. STRAHAN.

THE existence of anthracite in the South Wales coalfield was well known to the earliest miners of whom records exist, and the part of the coalfield to which anthracite was limited was roughly defined, so far as regards the small depths they were able to attain. Leland, for example, mentions that the coals of the Gwendraeth-fawr are anthracite (stone coals), while those of Llanelly are bituminous (ring coals).* The development of the coalfield, however, during the last 100 years has added much to the superficial observations first made, and has shown that the gradation into anthracite proceeds in accordance with certain general laws, the investigation of which seems likely to lead to results of both scientific and economic value.

The changes undergone by the coal present certain stages, which, though recognised commercially, are not capable of exact definition: from house-coal, or the most bituminous, the change is gradual into steam-coal, and from steam-coal into anthracite. The facts reported with respect to the changes are as follows:—

1st.—The anthracitic regions lie in the north-western corner of the Carmarthenshire, Brecknock, and Glamorganshire field, and in Pembrokeshire. In the former, which we may call the main coalfield, the seams become gradually less bituminous in approaching the anthracitic region. The change takes place

* "At *LLanelthle*, a Village of *Kidwelli* Lordship, a. vi. miles from *Kidwelli*, th Inhabitans digge Coles, elles scant in *Kidwelly* Land. Ther be ii. Maner of thes Coles. Ring Coles for Smith be blowid and waterid. Stones Cole be sumtime waterid, but never blowen. For blowing extinguishit them. So that *Vendwith Vaur* Coles be Stone Coles; *LLanethle* Coles Ring Colis."
("The Itinerary of John Leland the Antiquary," vol. 5. Published from the original Ms. in the Bodleian Library, by Thomas Hearne, M.A., *Oxford*, 1744.)

from east to west along the north crop in the eastern end of the coalfield, from south-east to north-west nearer to Cardiff, and from south to north near Swansea and in the western part of the main coalfield. In other words, lines of equal anthracitisation circle round an area which extends from Kidwelly to Glyn Neath. In Pembrokeshire all the coal is anthracitic.

2nd.—The seams all show the change on approaching the anthracitic region, but the higher seams show it later than the lower. Thus No. 2 Rhondda Coal keeps its character as a house-coal to within about 25 miles of the anthracite centre, and then becomes a steam-coal. The house-coals, about 400 yards below, become steam-coals about 30 or 40 miles from the anthracitic centre, and then occur as anthracite for a distance of about 25 miles. It follows that in any one deep shaft the shallower seams should be more bituminous than the deeper, which as a fact has been proved to be generally the case.

3rdly.—The loss of bituminous matter takes place at a more rapid rate in a south-to-north direction than in an east-to-west direction. This fact, taken in connection with the general form of the anthracitic region, so far as it has survived denudation, indicates that the original area of anthracitic coal was elongated in an east-and-west direction. It is obvious, moreover, that that area did not even approximately coincide with the existing coalfield, but lay, for the most part, outside it to the north and north-west.

There have been many speculations on the reasons for the diminution in bituminous matter. But while it was easy to find serious objection to every theory that has been advanced, the facts were not sufficiently definite to enable any fresh hypothesis to be put forward with confidence. A large number of analyses had been made, partly in connection with an official report written in 1848 by De la Beche and Playfair on "Coals suited to the Steam Navy," and partly for Dr. Percy for the purposes of his work on "Metallurgy." Of later years many analyses had been carried out by Mr. C. A. Seyler, to whom is due the credit of having taken the first steps towards a systematic classification of South Wales coals. Many others also had been furnished to colliery-proprietors by various analysts, but of these several were useless for the present purpose, some because the name of the seam was not given, others inasmuch as they were only proximate. Finally, a large series of analyses, including many of South Wales, had been collected in a useful publication by the Colliery Guardian Company.

It was clearly desirable, however, for the special purpose in view, that not only should all available analyses be collected and compared, but that all should be referred to their proper horizons in the Coal Measures, and that the series should be supplemented when necessary for the investigation of the change in character of any particular seam. Arrangements were commenced for the collecting and analysing of such further samples

as might be required in January, 1901, by the sanction of Sir A. Geikie, at that time Director-General of the Geological Survey.

In view of the difficulty of knowing where a seam of which a specimen was required was at the moment being worked, and of obtaining the consent of the colliery-proprietors to fresh analyses being published, the advice of the South Wales Institute of Engineers was sought, with the result that on the 14th of January the Council appointed a Committee of the following gentlemen as being representative of every part of the coalfield :—The President (Mr. Thomas Evens), Messrs. Archibald Hood, H. K. Jordan, H. W. Martin, W. D. Wight, John Roberts, Hugh Bramwell, Fox Tallis, W. Stewart, W. Forster Brown, James Barrow. Eventually the task of ascertaining in what localities specimens could be obtained, and of communicating with the colliery-proprietors, fell to the Secretary of the Institute, Mr. T. Jones Price, whose cordial co-operation in the work proved to be invaluable. It was arranged with the colliery-proprietors that the analyses might be published, but that the localities from which the samples were obtained should be indicated by numbers only on a general map of the coalfield, and that the names of the collieries should not be mentioned. These conditions have been complied with.

In selecting specimens with the special object in view of illustrating the progress of the change in the composition of the coal, it was obviously advisable to deal with each seam separately. It was useless, for example, to compare a seam high up in the Coal Measures in one locality with a seam near the base of the Coal Measures elsewhere. Specimens from the same seam, on the other hand, would be comparable in different localities, though they might be obtained from different depths below the surface. It seemed to be advisable, therefore, to select for the investigation a few of the more important seams, and especially those which could be recognised over wide areas. Subsequently difficulties arose in consequence of the selected seams not being accessible in regions from which specimens were desired, and from other causes, while at the same time, from a rigid adherence to this scheme, opportunities of getting specimens from other seams would have been lost. The bulk of the published analyses, moreover, could not have been utilised. While, therefore, the desirability of obtaining a series of analyses illustrative of the changes in any one seam was not lost sight of, analyses of other coals of local importance have been included in the lists.

The collecting was commenced in 1901. It was arranged that the collector should be conducted, at every colliery he visited, to a working face where a typical development of the seam was exhibited, and that coal should be cut by an official of the colliery from all parts of the face, except those partings which are separated out by the miners. The coal thus cut was sampled by the collector in the usual manner, and the sample was enclosed in a box with a printed form filled in by the colliery-manager, on which were given the name and section of the seam, depth from surface, and other particulars.

CHAPTER II.

Sequence of the Seams.

By A. Strahan.

In view of the importance of considering the analyses of each seam separately, it becomes necessary to correlate, as far as possible, the seams of one part of the coalfield with those of another. In Plate 2 a series of vertical sections ranging from the east to the west end of the coalfield, is arranged with the principal seam of the most productive belt of the measures as a datum-line. Above and below the datum-line the various seams referred to in the table of analyses are inserted in their proper respective positions, but the table does not profess to give a complete list of all the seams known to occur in South Wales.

The recognition of the seam selected as a datum-line may be regarded as fairly certain from Pontypool westwards so far as the Neath Valley along the North Crop. Its identification as the Nine Foot near Aberavan in the South Crop, and as the Stanllyd or Big Vein in the more western sections, is open to doubt. But though individual seams are difficult to identify, the productive belt as a whole is easily recognised. The identification of the principal seam in this belt as one and the same seam, while admittedly unproved, is put forward as the most probable, and as being certainly not far from the truth. The analyses of the seam thus selected are inserted on the map forming Plate 4.

No individual correlation of the seams below the datum-line has been attempted. Locally some of them are valuable, but no one of them can be traced continuously over more than a small part of the coalfield. The analyses of these coals are grouped together in the map forming Plate 3.

The group of veins shown close above the datum-line in the four right-hand columns of Plate 2 yield the bulk of the best smokeless steam-coal of Glamorganshire. From Pontypool to the Neath Valley they are individually recognisable along the northern and central parts of the coalfield. West of that valley and in the South Crop the seams in a corresponding position change greatly in number and thickness, and no correlation of individual seams has been attempted. The analyses of the veins belonging to this horizon are presented in the map forming Plate 5.

The identification of the seam known as the Tillery Vein in Monmouthshire, with that known as the No. 2 Rhondda Seam

in Glamorganshire, and by other names in various parts of the coalfield, has been discussed in every succeeding Part of the Memoir on the South Wales Coalfield, and needs no further comment here. The analyses are shown on Plate 6.

The correlation of the Mynyddislwyn Vein with the Llantwit No. 3, the Wernffraith or Swansea Four Feet and the Box Big of Llanelly, is less capable of proof. Its correlation with the Llantwit No. 3 has been adopted in accordance with arguments brought forward by Mr. H. K. Jordan* in preference to the correlation with Llantwit No. 1 which was originally selected. The reasons for identifying Llantwit No. 3 with the Wernffraith or Swansea Four Feet vein are explained in "The Country around Swansea" (*Mem. Geol. Survey*), 1907, pp. 33-35, but by some authorities the Graigola Vein of Swansea is regarded as the equivalent of the Mynyddislwyn. That the Wernffraith., Swansea Four Feet and Box Big are one and the same vein is generally admitted. The analyses of the Mynyddislwyn Vein and its supposed equivalents are inserted in Plate 7, together with those of some of the veins which occur between it and the No. 2 Rhondda seam.

Two facts are illustrated by the series of sections forming Plate 2. Firstly, that the measures expand rapidly from east to west, the thickness intervening between the Mynyddislwyn and the lowest seam at Pontypool being little more than a quarter of the thickness between the Box Big and the lowest seam near Llanelly. Secondly, that an expansion takes place also from north to south, the thickness near Aberavan in the South Crop being considerably greater than that in the North Crop on the same line of longitude. One exception to this rule is to be observed: locally, near Pontypool, there is a southerly and easterly attenuation, the smallest thickness known in any part of the coalfield being found near Cwm Bran. The greatest thickness on the other hand is reached in the south-west part of the coalfield, where no less than 5,700 feet intervene between the Box Big and the datum-line. Whether there is any connection between the varying thickness of the measures and the anthracitic character of the coal will be discussed in Chapter IX.

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* *Proc. S. Wales Inst. Eng.*, vol. xxiii (1903), pp. 190-204, 323-337.

CHAPTER III.

Analytical Methods and Table of Analyses.

By W. Pollard.

The methods of analysis employed for those analyses made in the Geological Survey Laboratory are given rather fully, as it is well known that variation in method in coal-analysis (especially in the determination of volatile matter) may produce variation in results. For the most part the methods are practically the same as those recommended by the Commission on Coal-analysis of the American Chemical Society.*

Sampling.—The samples as received at the laboratory are packed in large biscuit-tins enclosed in wooden boxes. The weight of the sample is 20 to 30 lbs. Usually it contains no large pieces, but all larger than a small orange are broken and the whole sample passed through a 1-in. sieve. After thorough mixing it is quartered in the usual way, the rejected half being at once replaced in the tin, whilst the other half is passed through a small Marsden-Blake crusher, and reduced by quartering to about 1 lb. This is then ground in a coffee-mill, set fine, halved and transferred to two-stoppered bottles, the one for analysis, the other being tied down and sealed, in case it be required for future reference. The sample obtained by grinding in the coffee-mill is used for moisture and volatile matter estimations. For all other estimations a portion of this is further ground to pass the 50-hole sieve. The moisture is separately estimated in this sample also, so that all estimations can be calculated on coal as received. When coal-analysis was first started in this laboratory volatile matter was determined on both samples, but as in no case were any great differences found, the determination on the fine (50-hole) sample was discontinued.

For the estimation of specific gravity a special sample is taken from the tin, and that portion only is used which passes an 8-hole and is retained on a 16-hole sieve. Moisture and ash are separately estimated on this sample in order to get the density of the dry coal, and an approximation to that of the pure coal.

Moisture.—This is estimated in all three samples. One gramme of coal is heated in a Victor-Meyer toluene bath for one hour exactly. The coal is weighed off between clipped watch-glasses, heated uncovered, covered immediately on removal from the toluene bath, and allowed to cool in a desiccator. It is weighed half an hour after removal from the bath. This method has been used in preference to that of drying *in vacuo* with sulphuric acid in a Hempel desiccator, as it is believed to be

* *Journ. Am. Chem. Soc.*, 1899, vol. xxi, p. 1,116.

the more generally in use in other laboratories, although in many cases less moisture is found by this method. A discussion on this point is to be found in the *Journ. Am. Chem. Soc.* (*loc. cit.*).

Duplicate estimations should agree within ·1 per cent.

Volatile Matter.—One gramme of coal is heated for seven minutes exactly in a platinum-crucible with well-fitting cover supported on a platinum-triangle over a bunsen giving a flame 20 cm. high. The bottom of the crucible should be 8 cm. above the mouth of the burner; gas-pressure should be 50 mm. of water. The particulars of the crucible used are:—Height, 40 mm.; diam. at base 24 mm., at top 34 mm. Capsule cover. A cylinder of clay or asbestos-board (of about 12 cm. diam.) should be used to prevent draughts from influencing the flame during the operation.

Loss in weight minus moisture gives volatile matter.

Duplicates should agree within ·15 per cent. on coals, with 15 per cent. volatile matter and under, and ·30 per cent. on coals with over 15 per cent.

The value found for volatile matter depends to some extent on the size of crucible, tightness of cover, strength of flame, &c.; it is of importance therefore to work under as constant conditions as possible. With some coals at times a small explosion occurs after about one minute's heating, in which case the experiment should be discarded, otherwise too much volatile matter will be found. The cover of the crucible should fit so as to allow the egress of the volatile matter as easily as possible, but prevent the air from getting at the coke more than can be prevented. Meade and Attix* suggested heating a second time under identical conditions and subtracting the second loss from the first. This was tried in several cases, but did not appear to offer any distinct advantage over the other method.

Ash.—(See also under "Combustion.") The ash left in the platinum-boat after combustion has invariably been taken as representing the ash in the coal. Of all the constituents ash is probably the least accurately determinable (and hence oxygen also), a point that is gone into under "Accuracy of Coal Analyses" on page 29.

Duplicates should agree within ·1 per cent. on coals with less than 4 per cent. ash, and ·2 per cent. on coals with more than 4 per cent. ash.

Fixed Carbonaceous Residue.—This is obtained by subtracting the sum of the percentages of ash, moisture, and volatile matter from 100.

* *Journ. Am. Chem. Soc.*, 1899, vol. xxi, p. 1,137.

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...ssium sulphide solution. Distil (using a good splash-head), ...ecting in 20 c.c. $\frac{n}{10}$ acid. Titrate back with $\frac{n}{10}$ alkali, using ...thyl orange as indicator.

The mercury, and hence the potassium sulphide, may be ...ensed with,* the only difference apparently being that ... the mercury shorter heating is needed. Blind experiments ...uld be made and the correction applied. Duplicates should ...e within ·1 per cent.

Combustion.—(Carbon, hydrogen and ash.) Jena-glass combustion-tubes, about 110 cm. long and 12-15 mm. internal diameter, are best used. They are filled as follows:—

10 cm. space at each end.
6 to 8 cm. copper-oxide roll.
16 to 20 cm. space for boat.
45 cm. copper-oxide.
8 cm. lead-chromate pumice.
10 cm. silver spiral.

The furnace should be about 36 inches long; that used in this laboratory is a Fletcher combustion-furnace No. 2. The boat is of platinum, 10 cm. long. The purifying train (one for air and one for oxygen with a three-way tap so that the gas can be changed at once) consists of an Emmerling's absorption tube and a washbottle with 1 in 2 potash, one washbottle with concentrated sulphuric acid, followed by two U-tubes filled with pumice saturated with concentrated sulphuric acid.† Between the three-way tap and the combustion-tube a small sulphuric acid washbottle is placed (so that the rapidity of the gas current can be easily watched), followed by a small mercury trap. For the collection of the water a U-tube filled with pumice saturated with sulphuric acid is used. Before each combustion [illegible] filled with acid overnight, the acid being drained [illegible] weighing. Geissler bulbs, with an 8 cm. drying-tube filled with freshly-crushed potash, are used to absorb the carbonic acid, followed by a small sulphuric acid U-tube to absorb the last traces of moisture, and finally a protecting tube of sulphuric acid pumice. It is hardly necessary to state that bulbs and tubes are refilled before each combustion.

The following points may be of use, although it is unnecessary to describe the combustion in detail. The weight of dry coal [illegible] as near ·5 gramme as possible, this having been found the most convenient amount to work with for accuracy. The [illegible] powdered coal (50-hole sample) should be used, and spread [illegible] thin a layer as possible in the boat. The boat and coal [illegible] be dried for one hour exactly in the toluene bath immediately before required. When the boat, after final weighing [illegible]

* Lunge. "Chem. Techn. Untersuchungsmethoden." [illegible] p. 228.

† The pumice should be ignited with sulphuric acid [illegible] chlorides, etc.

combustion, is placed in the combustion-tube, it should rest on a strip of platinum-foil; this prevents any chance of its sticking to the tube, and diminishes the chance of any copper oxide adhering to it. Before commencing to heat the boat the oxygen is turned on in a gentle current. The copper oxide and silver spiral should be at a bright-red heat, and the copper oxide roll and lead chromate pumice at a dull red heat. When these are at the required temperature the boat is gradually heated and the combustion carried out in the usual way.

Duplicates should agree within:—

Hydrogen - - -	·1	per cent.
Carbon - - - -	·2	„

It is important for the copper oxide to be hot enough before the coal is heated, as possibly methane is amongst the first of the volatile products to come off, and it is well known that this gas requires a high temperature for combustion. In two of the earlier combustions made in this laboratory there seemed some reason to suspect that some methane had escaped combustion, as the difference between the carbon and hydrogen of the lower to the higher results gave the ratios of

$$\begin{array}{llll} & C : H & & 1 : 3{\cdot}5 \\ \text{and} & C : H & & 1 : 3{\cdot}8 \end{array}$$

whilst in each case the ash agreed. On repeating these combustions concordant results with the higher values were obtained in each case. Another possible source of error, when duplicates agree in the hydrogen but not in the carbon and ash, may be due to incomplete combustion of the carbon. This was found to have occurred on more than one occasion, in each case the coal containing over 5 per cent. of ash, and having a high caking-power. It was, indeed, owing to this that a boat 10 cm. long has since been used instead of one of the usual size, as the half gram of coal can be spread out into a thin layer, thus reducing the chance of incomplete combustion. The following example illustrates this point. A boat 5 cm. long was used, and the caking-power of the coal was about 45.

——	1	2	3
C. - - -	79·72	79·97	80·13
H. - - -	4·75	4·76	4·82
Ash - - -	8·38	8·12	7·98

The hydrogens all agree within the limit of ·1 per cent., but the carbons vary. Nos. 2 and 3 are within the ·2 limit, but No. 1 is low. On looking at the ashes, however, it will be seen that the sum of ash and carbon is in each case the same.

It has been suggested that one cause of low carbon-results

might be due to some carbon monoxide escaping complete combustion to dioxide. At Mr. Seyler's suggestion a small wash-bottle, containing dilute sodium-palladium chloride solution, was placed behind the protecting U-tube, so that all gases from the combustion-tube, not previously absorbed by the U-tube and potash-bulbs, must pass through the solution, and thus render it possible to detect monoxide. On no occasion has there been any indication whatever of its presence, in spite of one or two low carbons which could not be accounted for, except by assuming a slight-leak between U-tube and potash-bulbs, though none could be detected.

Caking Power.—This determination is not capable of any great accuracy, but is sometimes of use for comparative purposes. The coal is powdered to pass the 50-hole sieve, and is mixed with varying proportions of dry sand, which passes the 40-hole and stops on the 50-hole sieve; the weight of the two together is 25 grams for each experiment. The charge is placed in a platinum-crucible, and heated exactly as for an estimation of volatile matter. After cooling, the cake is carefully removed from the crucible, placed on a flat surface, and a 500-gram weight carefully placed on it. When the cake *just* crushes the caking-power is reached. The caking-power is expressed as the weight of sand per unit weight of coal, thus:—

Sand.	Coal.	Caking Power.
20·0	5·0	4
22·5	2·5	9
24·0	1·0	24 etc.

It is important that the coal be as fresh from the pit as possible, as in many cases the caking-power has been found to decrease by keeping.

Specific Gravity.—Estimated in a specific-gravity bottle, on about 5 grams of the special sample already described. Air is removed by boiling. Moisture- and ash-determinations are specially made on this sample, so as to give data for calculating approximately the density of the dry ash-free coal.

To correct for ash, either ·01 may be deducted from the specific gravity for each per cent. of ash, or the specific gravity of the ash may be specially estimated and correction applied. In either case, the final result of correcting can only be regarded as approximate.

As an example of a possible error in the correction, where the specific gravity of the ash has been determined:—If the specific gravity of a coal containing 95 per cent. of pure coal and 5 per cent. pyrites (moisture and other ash-constituents are omitted

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for the sake of simplicity) be 1·300, taking the specific gravity of pyrites as 5·0, the specific gravity of the pure coal would be 1·251. But as 5 per cent. pyrites would become on ashing (assuming the reaction to be quantitative) 3·33 per cent. Fe_2O_3, and taking the specific gravity of Fe_2O_3 as 5·1, the specific gravity of the pure coal as found would be 1·268. As it happens, in this case the deduction of ·01 for each per cent. of ash would be the nearer, but in the case where the ash as obtained by analysis is the same as that really contained in the coal, the direct method would probably give the more accurate figure.

Analyses of the Coals of South Wales, from all Sources.

Abbreviations.

Geol. Surv.—Samples collected and analysed by the Geological Survey in the years 1901-7.

G.S. (C. A. S.)—Samples collected by the Geological Survey, but analysed by Mr. C. A. Seyler in the year 1905.

Adm. Rep.—"Report on the Coals suited to the Steam Navy," by Sir H. T. de la Beche and Dr. Lyon Playfair. 1st Rep., dated 1848; 2nd Rep., 1849; 3rd Rep., 1851. The First Report was printed in *Mem. Geol. Survey*, vol. ii, Part 2, pp. 539-630, 1848.

Percy, 37, p. 325.—" Metallurgy," by John Percy, M.D., F.R.S., F.G.S., Ed. 1875. The first number refers to the number of the analysis, the second to the page.

S.W. Inst. E.—Transactions and Proceedings of the South Wales Institute of Engineers.

C.G.—*Colliery Guardian.*

A.B.C. and C.—"Analyses of British Coals and Cokes collected and compared." Reprinted from the *Colliery Guardian.* (First issue in parts, not dated; 2nd issue in 1907.)

Inst. M.E.—Transactions of the Federated Institution of Mining Engineers.

Inst. C.E.—Proceedings of the Institution of Civil Engineers.

C.A.S.—Analyses made and communicated to the Geological Survey by Mr. C. A. Seyler.

Per C.A.B.—Analyses communicated to the Geological Survey, by Mr. Capel A. Branfill.

The carbon, hydrogen, oxygen and nitrogen are expressed in percentages calculated for the "pure coal," *i.e.* for the coal after deduction for moisture, ash, and combustible sulphur. Thus in analysis 1, C. 88·66 + H. 4·89 + O. 4·90 + N. 1·55 = 100.

The $\frac{C}{H}$ ratio is the relation of carbon to hydrogen. Thus in Analysis 1, $\frac{88{\cdot}66}{4{\cdot}89} = 18{\cdot}13$.

The percentage of volatile matter is calculated on the coal exclusive of moisture and ash.

The fuel-ratio is the relation of fixed carbonaceous residue to volatile matter. Thus in Analysis 1, $\frac{100-30{\cdot}80}{30{\cdot}80} = 2{\cdot}25$.

The specific gravity is determined on the coal as received from the colliery.

The ash is expressed in percentage of the dry coal, *i.e.* coal dried at 105° C.

Total Sulphur.—The method of M. W. & J. Atkinson has been used with only slight modification. The following description of the method is taken from the report of the Commission on Coal Analysis of the American Chemical Society.*

"One gramme of finely-ground coke or coal is mixed thoroughly with 5 grammes of dry sodium carbonate, spread evenly over the bottom of a flat or shallow platinum dish, and the latter placed on a rectangular rest made of clay pipe-stems inside a muffle, which though hot is still black. The temperature of the muffle should be raised gradually during half an hour to clear cherry-redness, and then kept at the latter temperature for 10 to 15 minutes. The sodium carbonate should not sinter or fuse. The mass should not be stirred. When the carbon is burned, usually in about 45 minutes in all, cool, digest with 100 to 200 c.c. of warm water, allow to settle, decant through a filter and wash twice by decantation, and then on the filter, adding a few drops of a solution of sodium chloride if the residue tends to pass through the filter. The filtrate is acidified with 12 c.c. concentrated hydrochloric acid, and precipitated with barium chloride."

To avoid any possibility of all the sulphur not being oxidised to sulphate before acidifying, a little (about 10 c.c.) bromine water has always been added after filtering and before acidifying. It is usually necessary to heat for longer than the 45 minutes to burn off all the carbon. With these slight differences the method has been adhered to with most satisfactory results. The muffles used have been Fletcher gas-muffles, Nos. 461 and 661. Blind experiments have always been made simultaneously with and separately from determinations of sulphur in coal, and in no case has any appreciable amount of sulphur been obtained from the gas. As it is almost invariably necessary to correct for traces of sulphur contained in the sodium carbonate used, it is always as well to make a blind experiment with each batch of sulphur-estimations.

Duplicates should agree within ·1 per cent.

Sulphur in Ash—This is obtained from the ash from the combustion. The ash is transferred to a dish, hydrochloric acid added, evaporated to dryness, taken up with hydrochloric acid and hot water, filtered, and the sulphur in the filtrate precipitated with barium chloride. The amount of sulphur obtained here, subtracted from the total sulphur, gives the Combustible Sulphur.

Nitrogen.—Estimated by Kjeldahl's method. 1 gramme of coal is heated with 20 c c. strong sulphuric acid, 8 grammes dry potassium sulphate and a bead of mercury, till colourless. Allow to cool, pour into a flask of about 1,000 c.c. capacity containing about 200 c.c. water, rinse out, etc., and add 80 c.c. of a 50 per cent. sodium hydrate solution and 20 c.c. of a 5 per cent.

* *Ib.*, p. 1,116.

potassium sulphide solution. Distil (using a good splash-head), collecting in 20 c.c. $\frac{n}{10}$ acid. Titrate back with $\frac{n}{10}$ alkali, using methyl orange as indicator.

The mercury, and hence the potassium sulphide, may be dispensed with,* the only difference apparently being that with the mercury shorter heating is needed. Blind experiments should be made and the correction applied. Duplicates should agree within ·1 per cent.

Combustion.—(Carbon, hydrogen and ash.) Jena-glass combustion-tubes, about 110 cm. long and 12-15 mm. internal diameter, are best used. They are filled as follows:—

10 cm. space at each end.
6 to 8 cm. copper-oxide roll.
16 to 20 cm. space for boat.
45 cm. copper-oxide.
8 cm. lead-chromate pumice.
10 cm. silver spiral.

The furnace should be about 36 inches long; that used in this laboratory is a Fletcher combustion-furnace No. 2. The boat is of platinum, 10 cm. long. The purifying train (one for air and one for oxygen with a three-way tap so that the gas can be changed at once) consists of an Emmerling's absorption-tube and a washbottle with 1 in 2 potash, one washbottle with concentrated sulphuric acid, followed by two U-tubes filled with pumice saturated with concentrated sulphuric acid.† Between the three-way tap and the combustion-tube a small sulphuric acid washbottle is placed (so that the rapidity of the gas-current can be easily watched), followed by a small mercury-trap. For the collection of the water a U-tube filled with pumice saturated with sulphuric acid is used. Before each combustion this is filled with acid overnight, the acid being drained off just before weighing. Geissler bulbs, with an 8 cm. drying-tube filled with freshly-crushed potash, are used to absorb the carbonic acid, followed by a small sulphuric acid U-tube to absorb the last traces of moisture, and finally a protecting tube of sulphuric acid pumice. It is hardly necessary to state that bulbs and tubes are refilled before each combustion.

The following points may be of use, although it is unnecessary to describe the combustion in detail. The weight of dry coal is as near ·5 gramme as possible, this having been found the most convenient amount to work with for accuracy. The finely powdered coal (50-hole sample) should be used, and spread in as thin a layer as possible in the boat. The boat and coal should be dried for one hour exactly in the toluene bath immediately before required. When the boat, after final weighing before

* Lunge. "Chem. Techn. Untersuchungsmethoden," 4th ed., vol. i, p. 228.

† The pumice should be ignited with sulphuric acid before use to expel chlorides, etc.

combustion, is placed in the combustion-tube, it should rest on a strip of platinum-foil; this prevents any chance of its sticking to the tube, and diminishes the chance of any copper oxide adhering to it. Before commencing to heat the boat the oxygen is turned on in a gentle current. The copper oxide and silver spiral should be at a bright-red heat, and the copper oxide roll and lead chromate pumice at a dull red heat. When these are at the required temperature the boat is gradually heated and the combustion carried out in the usual way.

Duplicates should agree within:—

Hydrogen - - - -	·1 per cent.
Carbon - - - - -	·2 „

It is important for the copper oxide to be hot enough before the coal is heated, as possibly methane is amongst the first of the volatile products to come off, and it is well known that this gas requires a high temperature for combustion. In two of the earlier combustions made in this laboratory there seemed some reason to suspect that some methane had escaped combustion, as the difference between the carbon and hydrogen of the lower to the higher results gave the ratios of

$$\text{C : H} \qquad 1 : 3{\cdot}5$$
$$\text{and C : H} \qquad 1 : 3{\cdot}8$$

whilst in each case the ash agreed. On repeating these combustions concordant results with the higher values were obtained in each case. Another possible source of error, when duplicates agree in the hydrogen but not in the carbon and ash, may be due to incomplete combustion of the carbon. This was found to have occurred on more than one occasion, in each case the coal containing over 5 per cent. of ash, and having a high caking-power. It was, indeed, owing to this that a boat 10 cm. long has since been used instead of one of the usual size, as the half gram of coal can be spread out into a thin layer, thus reducing the chance of incomplete combustion. The following example illustrates this point. A boat 5 cm. long was used, and the caking-power of the coal was about 45.

—	1	2	3
C. - - - -	79·72	79·97	80·13
H. - - - -	4·75	4·76	4·82
Ash - - - -	8·38	8·12	7·98

The hydrogens all agree within the limit of ·1 per cent., but the carbons vary. Nos. 2 and 3 are within the ·2 limit, but No. 1 is low. On looking at the ashes, however, it will be seen that the sum of ash and carbon is in each case the same.

It has been suggested that one cause of low carbon-results

might be due to some carbon monoxide escaping complete combustion to dioxide. At Mr. Seyler's suggestion a small wash-bottle, containing dilute sodium-palladium chloride solution, was placed behind the protecting U-tube, so that all gases from the combustion-tube, not previously absorbed by the U-tube and potash-bulbs, must pass through the solution, and thus render it possible to detect monoxide. On no occasion has there been any indication whatever of its presence, in spite of one or two low carbons which could not be accounted for, except by assuming a slight-leak between U-tube and potash-bulbs, though none could be detected.

Caking Power.—This determination is not capable of any great accuracy, but is sometimes of use for comparative purposes. The coal is powdered to pass the 50-hole sieve, and is mixed with varying proportions of dry sand, which passes the 40-hole and stops on the 50-hole sieve; the weight of the two together is 25 grams for each experiment. The charge is placed in a platinum-crucible, and heated exactly as for an estimation of volatile matter. After cooling, the cake is carefully removed from the crucible, placed on a flat surface, and a 500-gram weight carefully placed on it. When the cake *just* crushes the caking-power is reached. The caking-power is expressed as the weight of sand per unit weight of coal, thus:—

Sand.	Coal.	Caking Power.
20·0	5·0	4
22·5	2·5	9
24·0	1·0	24 etc.

It is important that the coal be as fresh from the pit as possible, as in many cases the caking-power has been found to decrease by keeping.

Specific Gravity.—Estimated in a specific-gravity bottle, on about 5 grams of the special sample already described. Air is removed by boiling. Moisture- and ash-determinations are specially made on this sample, so as to give data for calculating approximately the density of the dry ash-free coal.

To correct for ash, either ·01 may be deducted from the specific gravity for each per cent. of ash, or the specific gravity of the ash may be specially estimated and correction applied. In either case, the final result of correcting can only be regarded as approximate.

As an example of a possible error in the correction, where the specific gravity of the ash has been determined:—If the specific gravity of a coal containing 95 per cent. of pure coal and 5 per cent. pyrites (moisture and other ash-constituents are omitted

No. on Plates 1 and 3-7.	1-inch map.	Local Name of Vein.	Colliery.	Authority.
41	231	Big - - -	Ystradgynlais -	A.B.C. & C. (1st Ed.), p. 123
42	248	Yard - -	Aberaman -	C.G., lxxi., p. 541 -
43	247	Average of Four and Six Foot	Llanmorlais -	„ p. 1,015 -
44	230	Stanllyd - -	Park and Blaina	A.B.C. & C. (Ed. 1907), p. 367
45	232	Old - - -	- -	Geological Survey -
46	232	Old or Lower Four Foot	Nant-y-glo and Blaina	Percy, 122, p. 569 -
47	231	Peacock - -	- -	C.A.S. - - -
48	230	Little [Brass] -	- -	„ - - - -
49	230	Peacock - -	- -	„ - - - -
50	230	Brass - -	Cwmllynfell -	Adm. Rept., i, pp. 34 & 58
51	230	Peacock - -	- -	C.A.S. - - -
52	231	Peacock - -	Gwaunclawdd -	A.B.C. & C. (1st Ed.), p. 123
53	230	Peacock - -	- -	C.A.S.- - - -
54	248	No. 2 Rhondda	- -	S.W. Inst. E., xxi, p. 511
55	248	Rock Vawr -	Bronbil -	Adm. Rept., ii, pp. 21 & 51
56	248	No. 2 Rhondda	- -	C.A.S. - - -
57	249	Rock - -	Machen - -	Adm. Rept., iii, pp. 39 & 51
58	248	No. 2 Rhondda	- -	C.A.S.- - - -
59	248	Rock Fawr -	Bronbil - -	Adm. Rept. iii, pp. 43 & 52
60	230	Upper or Pen-y-Graig	Cwm Clic - -	Percy, 130, p. 569 -
61	248	No. 2 Rhondda-	Glyn Corwg -	Percy, [the mean of] 118–120, p. 569
62	247	Penlan Gas-coal	Penlan - -	A.B.C. & C. (1st Ed.), p. 82
63	232	Meadow - -	- -	Geological Survey -
64	232	Mynydd Black -	Blaenserchan -	A.B.C. & C. (Ed. 1907), p. 129
65	232	Meadow - -	- -	Geological Survey -
66	247	Cribbwr - -	Morfa - -	S.W. Inst. E., xxi, p. 516
67	231	Four Foot or Cornish	Abercraf - -	A.B.C. & C. (1st Ed.), p. 126
68	231	Cornish - -	Pwllfaron - -	Percy, 121, p. 569 -
69	247	Four Foot -	Morfa - -	S.W. Inst. E., xxi, p. 519
70	230	Wernffraith -	Primrose - -	C.G., lxxi, p. 1,015 -

No. on Plates 1 and 3-7.	C.	H.	O.	N.	$\frac{C}{H}$ ratio.	Volatile Matter.	Fuel-ratio.	Sp. Gr.	Ash.
41	93·88	3·65	1·85	·62	25·72	—	—	—	2·1
42	—	—	—	—	—	10·73	8·32	—	2·4
43	—	—	—	—	—	24·00	3·17	—	2·0
44	94·32	3·68	2·00		25·63	5·15	18·42	—	1·1
45	87·93	5·30	5·50	1·27	16·59	31·48	2·18	1·320	5·0
46	90·74	5·23	4·03		17·35	22·72	3·40	—	6·0
47	94·02	3·96	2·30		23·74	7·20	12·88	—	2·4
48	94·19	3·58	2·23		26·31	5·12	18·53	—	1·6
49	93·67	3·73	2·60		25·11	5·84	16·12	—	1·4
50	93·60	3·54	2·64	·22	26·44	7·21	12·87	1·375	1·5
51	93·39	3·66	2·95		25·52	5·25	18·04	—	1·8
52	93·70	3·90	2·40		24·03	6·34	14·76	—	2·3
53	94·02	3·66	2·32		25·69	5·76	16·36	—	2·2
54	89·74	5·67	4·59		15·83	27·60	2·62	—	—
55	85·23	4·80	9·35	·62	17·76	40·56	1·47	1·292	7·5
56	91·78	5·13	3·19		17·89	18·31	4·47	—	6·4
57	75·00	5·15	18·85	1·00	14·56	36·19	1·76	1·297	3·8
58	92·64	4·74	2·62		19·54	17·33	4·77	—	6·6
59	84·78	5·57	8·94	·71	15·22	43·26	1·31	1·301	4·3
60	93·58	4·05	2·37		23·11	7·62	12·12	—	5·3
61	91·66	4·85	3·49		18·91	19·55	4·12	—	4·5
62	—	—	—	—	—	33·50	2·13	1·257	2·1
63	87·97	5·26	5·25	1·52	16·72	34·34	1·91	1·330	8·1
64	87·52	5·16	6·26	1·06	16·96	—	—	—	3·1
65	87·16	5·42	5·83	1·59	16·08	33·84	1·95	1·326	6·5
66	87·50	5·15	7·35		16·99	28·90	2·46	—	1·3
67	93·69	3·74	2·57		25·05	6·73	13·85	—	2·0
68	93·83	3·95	2·22		23·75	6·78	13·75	—	4·1
69	85·20	5·40	9·40		15·78	30·60	2·27	—	2·6
70	92·45	4·80	2·75		19·26	—	—	—	3·0

No. on Plates 1 and 3-7.	1-inch map.	Local Name of Vein.	Colliery.	Authority
71	247	Four Foot -	Near Morriston	Adm. Rept. i, pp. 32 & 60
72	249	Mynyddislwyn -	- -	Geological Survey -
73	249	Bedwas Vein -	Bedwas - -	Adm. Rept. i, pp. 40 & 63
74	247	Five Foot -	Mynydd-Newydd	S.W. Inst. E., xxi, p. 508
75	247	Penyfilia or Five Foot	Mynydd-Newydd	Adm. Rept., i, pp. 29 & 61
76	247	Clyndie [Clyndu] or Five Foot	Llangyfelach -	Adm. Rept., i, pp. 24 & 61
77	231	Six Foot - -	Glyncastle -	Inst. M.E., xii, p. 238; also A.B.C. & C. (Ed. 1907), p. 386
78	248	Two-foot-nine -	Blaen Rhondda	Percy, 98, p. 333
79	248	Two foot-nine -	Dunraven- -	Percy, 101, p. 333 -
80(2)	231	Gadley Four Foot	1-3rd mile w. of Aberdare -	Adm. Rept., ii, p. 35 & 53
81	248	UpperFourFoot	Ffaldau - -	S.W. Inst. E., xxi, p. 508; C.G., lxx, p. 639
82	248	UpperFourFoot	Ynysyfaio -	C.G. lxxv, p. 570, and lxxxiv, p. 1,081
83	248	UpperFourFoot	Dunraven- -	Percy, 102, p. 333 -
84	248	UpperFourFoot	Blaen Rhondda	Percy, 99, p. 333 - -
85(3)	231	UpperFourFoot	Dowlais - -	Percy, 36, p. 325 - -
86	248	Four Foot of Dyffryn	Aberdare Valley	Adm. Rept., i, pp. 25 & 61
87	232	Four Foot -	EbbwValeIronworks	Adm. Rept., i, pp. 42 & 64
88	231	Four Foot -	Hill's Plymouth Merthyr	Adm. Rept., ii, pp. 42 & 65
89	248	UpperFourFoot	Aberaman -	Adm. Rept. iii, pp. 26 & 49
90	232	Ell - - -	Blaina - -	Percy, 6, p. 322 - -
91	230	Graigola - -	Primrose - -	C. G., lxxi, p. 1015 -
92	232	Three Quarter -	Blaina - -	Percy, 7, p. 322 -
93	232	Three Quarter (top vein)	Nantyglo and Blaina	Percy, 123, p. 569 -
94	249	Three Quarter -	- -	Geol. Surv. - - -
95	232	Three Quarter Rock	Nr. Varteg Iron Co's Works	Adm. Rept., i, pp. 30 & 62
96	232	Three Quarter -	- -	Geol. Surv. - - -
97	232	Three Quarter -	- -	Geol. Surv. - -
98	230	Six Feet - -	Graigola Merthyr	C. G. lxxi, p. 1015
99	230	Six Foot - -	Primrose	S.W. Inst. E., xxi, p. 508
100	247	SixFeet(partof)	Mynydd-newydd	S.W. Inst. E., xxi, p. 513

(2) and (3) See note at end of Table.

No. on Plates 1 and 3-7.	C.	H.	O.	N.	C/H ratio.	Volatile Matter.	Fuel-ratio.	Sp. Gr.	Ash.
71	91·81	4·66	3·34	·19	19·70	18·10	4·53	1·31	3·4
72	86·94	5·64	5·84	1·58	15·41	37·52	1·66	1·336	7·3
73	90·01	6·71	1·67	1·61	13·41	30·41	2·29	1·32	6·9
74	91·66	4·87	3·47		18·82	18·80	4·32	—	6·4
75	88·66	6·03	3·68	1·63	14·70	26·04	2·84	1·31	3·2
76	91·18	3·97	4·85	trace	22·97	15·97	5·26	1·358	6·1
77	93·63	4·01	1·91	·45	23·35	—	—	—	1·3
78	94·11	4·19	1·70		22·46	11·03	8·06	—	2·8
79	93·35	4·15	2·50		22·49	11·16	7·96	—	1·4
80	93·77	4·64	·65	·94	20·21	11·22	7·91	1·327	4·9
81	91·31	4·95	3·74		18·45	18·78	4·33	1·29	·9
82	—	—	—	—	—	12·02	7·32	—	1·0
83	91.86	3·93	4·21		23·37	10·61	8·42	—	3·8
84	92·74	3·96	3·30		23·42	10·26	8·75	—	4·8
85	90·92	4·51	3·31	1·26	20·16	—	—	—	1·2
86	92·93	4·91	·63	1·53	18·93	16·23	5·16	1·326	3·3
87	92·10	5·28	·40	2·22	17·44	22·84	3·38	1·275	1·5
88	91·44	4·13	3·95	·48	22·14	18·19	4·50	1·359	2·4
89	93·40	4·39	·97	1·24	21·27	15·22	5·57	1·305	1·5
90	84·42	5·48	8·41	1·69	15·41	—	—	—	1·5
91	92·73	4·64	2·63		19·98	—	—	—	4·7
92	86·25	5·90	6·13	1·72	14·62	—	—	-	2·5
93	89·81	5·11	5·08		17·58	25·03	2·99	—	4·2
94	87·81	5·09	5·64	1·46	17·25	32·39	2·09	1·314	6·2
95	87·19	5·72	5·85	1·24	15·24	42·12	1·37	1·34	11·0
96	86·63	5·13	6·85	1·39	16·89	33·92	1·95	1·307	4·6
97	87·20	5·10	6·36	1·34	17·10	32·78	2·05	1·327	7·0
98	—	—	—	—	—	12·53	6·98	—	1·7
99	91·70	4·80	3·50		19·10	15·70	5·37	—	4·6
100	90·75	4·73	4·52		19·19	20·30	3·93	—	6·0

No. on Plates 1 and 3-7.	1-inch map	Local Name of Vein.	Colliery.	Authority.
101	247	Binea or Loughor Fiery	Binea Farm -	Adm. Rept. i, pp. 28 & 59
102	247	Brynddwey -	Neath Abbey -	Adm. Rept., ii, pp. 13 & 50
103	230	Graigola - -	Ynysymond -	Adm. Rept., i, pp. 31 & 57
104(4)	247	Ward's Fiery -	1½ miles E. of Llanelly	Adm. Rept., i, pp. 27 & 58
105	246	Fiery - -	Old Castle -	Adm. Rept., i, pp. 26 & 58
106	247	Graigola - -	Birchgrove -	Adm. Rept., iii, pp. 21 & 48
107	247	Brynddwey -	Neath - -	Inst. C.E., viii, p. 101
108	230	Graigola - -	Waun-y-coed -	Percy, 89, p. 333 - -
109	232	Red - - -	- -	Geol. Surv. - - -
110	232	Big - - -	- -	Geol. Surv. - - -
111	249	Big - - -	Tirpentwys -	A. B. C. & C. (Ed. 1907), p. 132
112	230	Tregloin - -	- -	C.A.S. - - -
113(5)	230	Tregloin - -	- -	C.A.S. - - -
114	247	Cadoxton - -	Cadoxton - -	Adm. Rept., iii, pp. 16 & 47
115	247	Hughes - -	- -	C. A. S. - - -
116	247	Slatog - -	Weigfawr -	S.W. Inst. E., xxi, p. 523
117	247	Rotten or Bodor	Weigfawr -	S.W. Inst. E., xxi, p. 519
118	247	Curly - -	Weigfawr -	S.W. Inst. E., xxi, p. 519
119	247	Hedley's - -	Cwrt-y-bettws -	S.W. Inst. E., xxi, p. 508
120	247	Hughes - -	Cwrt-y-Bettws -	C.G., lxxi, p. 1015
121	247	Hughes - -	Weigfawr -	S.W. Inst. E., xxi, p. 523
122	247	Three Foot -	Mynydd-newydd	S.W. Inst. E., xxi, p. 508
123(6)	249	Charcoal - -	Abercarn -	Adm. Rept., iii, pp. 33 & 50
124	230	Lower or Welsh	Cwm Clic -	Percy, 131, p. 569
125	248	No. 3 Rhondda	Penrhiw - -	A.B.C. & C. (Ed. 1907), p. 392
126	248	Graig - -	Dunraven -	Percy, 100, p. 333 -
127	248	Graig - -	Blaen Rhondda	Percy, 97, p. 333 -
128(7)	230	Red - -	Pwllbach -	S.W. Inst. E., xxi, p. 506
129	231	Red - -	Dillwyn - -	A.B.C. & C. (Ed. 1907), p. 390)

(4) to (7)—see notes at end of Table.

No. on Plates 1 and 3-7.	C.	H.	O.	N.	C / H ratio.	Volatile Matter.	Fuel-ratio.	Sp. Gr.	Ash.
101	92·61	4·84	1·06	1·49	19·13	12·39	7·08	1·304	4·0
102	93·57	5·31	—	1·12	17·62	40·00	1·50	1·310	3·6
103	88·12	3·99	7·46	·43	22·09	14·99	5·67	1·30	3·2
104	94·68	4·23	—	1·09	22·38	—	—	1·344	7·0
105	90·14	5·03	3·48	1·35	17·92	20·77	3·82	1·289	2·6
106	88·96	4·38	5·89	·77	20·31	15·59	5·41	1·360	4·4
107	85·33	5·32	7·66	1·69	16·04	—	—	—	5·1
108	93·08	4·47	2·45		20·82	13·96	6·16	—	1·9
109	87·77	4·97	5·94	1·32	17·66	31·08	2·22	1·325	3·4
110	87·81	5·12	5·65	1·42	17·15	32·97	2·03	1·338	7·2
111	90·58	5·39	3·39	·64	16·81	—	—	1·319	5·0
112	94·16	3·66	2·18		25·73	5·20	18·23	—	2·0
113	93·79	3·63	2·58		25·84	5·41	17·48	—	4·3 1·3
114	92·64	4·58	1·67	1·11	20·23	18·67	4·36	1·378	3·6
115	92·46	4·36	3·18		21·16	11·74	7·52	—	2·2
116	83·63	5·28	11·09		15·84	35·70	1·80	—	4·4
117	85·69	5·81	8·50		14·75	33·60	1·97	—	3·3
118	85·93	5·92	8·15		14·52	37·70	1·65	—	5·5
119	91·69	4·59	3·72		19·98	14·75	5·77	—	4·4
120	91·52	4·71	3·77		19·43	—	—	—	4·0
121	77·40	4·67	17·93		16·57	51·50	·94	—	27·5
122	91·46	5·02	3·49		18·22	19·70	4·08	—	4·1
123	84·56	6·57	8·07	·80	12·87	32·26	2·10	1·334	2·0
124	93·71	3.69	2·60		25·40	7·44	12·44	—	4·4
125	88·44	5·32	5·11	1·13	16·62	25·40	2·94	—	1·6
126	91·66	4·71	3·63		19·46	19·61	4·10	—	3·4
127	92·57	4·72	2·71		19·61	16·35	5·12	—	3·3
128	92·48	4·03	3·49		22·95	6·04	15·56	—	1·7 5·5
129	93·56	3·48	2·21	·75	26·89	—	—	—	3·9

No. on Plates 1 and 3-7.	1-inch map.	Local Name of Vein.	Colliery.	Authority.
130	230	Red - -	- -	C.A.S. - - -
131	230	Red - -	Cwm Gors .	A.B.C. & C. (Ed. 1907), p. 403
132	230	Red - -	- -	C.A.S. - - -
133	230	Red - -	Cawdor - -	S.W. Inst. E., xxi, p. 506
134	230	Red - -	Ynysygeinon	S.W. Inst. E., xxi, p. 506
135	230	Red - -	- -	C.A.S. - - -
136	230	Pontyberem No. 1 [Gras-uchaf]	Pontyberem -	A.B.C. & C. (1st Ed.), p. 58
137	230	Clynhebog [Lower Pump-quart]	Pontyberem -	A.B.C. & C. (1st Ed.), p. 58
138	230	Middle -	- -	C.A.S. - - -
139	230	Lower - -	- -	C.A.S. - - -
140	230	Lower Tri-chwart	- -	C.A.S. - - -
141	230	New Cross Hands [Lower Pumpquart]	New Cross Hands	A.B.C. & C. (1st Ed.), p. 83
142	230	Lower Pump-quart	- -	C.A.S. - - -
143	230	Lower Pump-quart	- -	C.A.S. - - -
144	229	Big - - -	-	C.A.S. - - -
145	229	Drap - -	- -	C.A.S. - - -
146	229	Green -	-	C.A.S. - - -
147	248	Cae David -	Ty-chwyth -	Percy, 72, p. 332
148	248	Six Foot - -	Dunraven -	Percy, 103, p. 333 -
149	248	Six Foot - -	Llynfi - -	Percy, 74, p. 332 -
150	248	Duffryn - -	Llynfi - -	Percy, 75, p. 332 -
151	248	Yard - -	Llynfi - -	Percy, 77, p. 332
152	247	Five Foot (top)-	- - -	Geol. Surv. - -
153	247	„ (middle)	- - -	„ - -
154	247	„ (bottom)	- - -	„ - -
155	247	„ (top) -	- - -	„ - -
156	247	„ (middle)	- - -	„ - -
157	247	„ (bottom)	- - -	„ - -
158	247	„ (top) -	- - -	„ - -
159	247	„ (middle)	- - -	„ - -
160	247	„ (bottom)	- - -	„ - -
161	230	Peacock - -	Brynhenllys -	Per C.A.B. - -
162	230	Big - -	Ynyscedwyn -	„ - - -
163	230	Peacock - -	Gilfach - -	„ - - -
164	231	Red - -	Dillwyn - -	„ - - -
165	230	Big - - -	Gwauncaegurwen	„ - - -
166	230	Peacock - -	„	„ - - -
167	230	Big - - -	Garnant - -	„ - -

No. on Plates 1 and 3-7.	C.	H.	O.	N.	$\frac{C}{H}$ ratio.	Volatile Matter.	Fuel-ratio.	Sp. Gr.	Ash.
130	93·03	3·51	3·46		26·50	7·73	11·94	—	3·6
131	94·08	3·79	2·13		24·85	6·48	14·43	—	2·7
132	93·39	4·09	2·52		22·83	7·39	12·53	—	1·9
133	93·42	4·02	2·56		23·24	6·50	14·38	—	2·8
134	92·58	3·91	3·50		23·68	7·70	11·98	—	3·0
135	93·33	3·93	2·74		23·75	6·53	14·31	—	2·0
136	—	—	—		—	5·39	17·54	—	1·7
137	—	—	—		—	5·54	17·04	—	·9
138	94·31	3·64	2·05		25·91	5·24	18·08	—	1·7
139	94·09	3·58	2·33		26·28	5·12	18·53	—	1·7
140	94·1	3·6	2·3		26·14	5·10	18·61	—	2·6
141	93·87	3·41	2·72		27·53	3·83	25·1	—	·8
142	93·00	3·68	3·32		25·27	5·20	18·28	—	1·1
143	94·38	3·14	1·16	·87	30·06	5·17	18·19	—	·8
144	93·83	3·74	2·43		25·09	6·72	13·87	—	1·4 3·3
145	92·59	4·54	1·30	1·57	20·39	—	—	—	1·4
146	93·98	3·88	2·14		24·22	6·71	13·90	—	2·4
147	87·99	5·64	6·37		15·60	34·35	1·91	—	4·2
148	92·73	3·95	3·32		23·48	12·03	7·31	—	3·0
149	91·25	4·84	3·91		18·85	20·17	3·96	—	2·0
150	89·75	4·92	5·33		18·24	23·33	3·29	—	3·9
151	90·53	4·98	4·49		18·18	23·17	3·32	—	2·6
152	92·65	4·45	1·30	1·60	20·81	17·63	4·67	1·365	6·4
153	90·58	4·33	3·61	1·48	20·89	19·55	4·12	1·358	6·1
154	91·49	4·45	2·49	1·57	20·58	17·75	4·63	1·332	5·1
155	90·91	4·79	2·70	1·60	18·98	22·71	3·40	1·337	6·2
156	88·64	4·72	5·00	1·64	18·77	27·21	2·67	1·365	8·4
157	89·98	4·82	3·54	1·66	18·67	23·62	3·23	1·321	5·2
158	92·40	4·38	2·04	1·18	21·10	16·47	5·07	1·369	5·9
159	91·36	4·32	2·73	1·59	21·15	17·70	4·65	1·365	5·7
160	90·48	4·34	3·66	1·52	20·85	15·99	5·25	1·353	5·6
161	92·13	3·76	4·11		24·54	—	—	—	1·4
162	92·46	3·20	4·34		28·87	—	—	—	1·6
163	93·92	3·57	2·51		26·26	—	—	—	1·0
164	93·42	3·39	1·65	1·54	27·54	9·00	10·11	—	1·8
165	94·49	3·67	1·84		25·77	—	—	—	1·7
166	93·80	3·16	3·04		29·64	—	—	—	2·3
167	93·17	2·12	4·71		43·85*	—	—	—	·4

* See footnote on p. 53.

No. on Plates 1 and 3-7.	1-inch map.	Local Name of Vein.	Colliery.	Authority.
168	231	Peacock - -	International -	„ - - -
169	231	Big - - -	„ -	„ - - -
170	230	Stanllyd - -	Caerbryn - -	„ - - -
171	231	Big - - -	Onllwyn - -	„ - -
172	231	Big - - -	Abercraf -	„ - - -
173	231	Eighteen Foot	Pwllfaron - -	Percy, 96, p. 333 -
174	249	Black - -	Glyn - -	A.B.C. & C. (Ed. 1907), p. 124
175	230	Big - - -	Blaencaegurwen	Per C.A.B. - - -
176	231	Four Foot -	Ystradgynlais -	„ - - -
177	228	Lower Level and Kilgetty	Bonville's Court and Kilgetty	Per C.A.B. and A.B.C. & C. (Ed. 1907), p. 404
178	229	Big - - -	Carway - -	A.B.C. & C. (Ed. 1907), p. 369
179	249	Brithdir - -	- -	Geol. Surv. - -
180	232	Mynyddislwyn	- -	„ -
181	232	Tillery - -	- -	„ - -
182	232	Red Ash - -	- -	„ - -
183	247	Five Foot (top)	- -	C.A.B. - - -
184	247	„ (middle)	- -	„ - - -
185	247	„ (bottom)	- -	„ - - -
186	247	Four Foot (top)	- -	„ - - -
187	247	„ (bottom)	- -	„ - - -
188	249	Black - -	Celynen - -	A.B.C. & C. (Ed. 1907), p. 127
189	249	Three-Quarter	Tirpentwys -	A.B.C. & C. (Ed. 1907), p. 132
190	229	Green Vein -	Cae Pontbren	A.B.C. & C. (Ed. 1907), p. 368
191	230	Peacock - -	Garnant - -	A.B.C. & C. (Ed. 1907), pp. 369 & 370
192	230	Stanllyd and Pumpquart	Emlyn - -	A.B.C. & C. (Ed. 1907), p. 371
193	247	Yankee - -	Clyne Valley -	A.B.C. & C. (Ed. 1907), p. 382
194	247	Three Foot -	Clyne Valley -	A.B.C. & C. (Ed. 1907), p. 384
195	247	[Box Big] - -	Glan Mwrwg -	A.B.C. & C. (Ed. 1907), p. 391
196	248	Forest - -	Penrhiw - -	A.B.C. & C. (Ed. 1907), p. 392
197	247	Lynch - -	Lynch - -	A.B.C. & C. (Ed. 1907), p. 394
198	228	Timber - -	Hill Pit, Hook -	A.B.C. & C. (Ed. 1907), p. 405

No. on Plates 1 and 3-7.	C.	H.	O.	N.	$\frac{C}{H}$ ratio.	Volatile Matter.	Fuel-ratio.	Sp. Gr.	Ash.
168	93·73	3·22	3·05		29·12	—	—	—	1·8
169	95·15	2·11	2·74		45·07*	—	—	—	2·3
170	93·20	3·12	2·74	·94	29·90	—	—	—	·7
171	—	—	—	—	—	5·48	17·26	—	1·2
172	93·16	3·52	3·32		26·43	—	—	—	1·4
173	93·52	3·82	2·62		24·48	7·02	13·25	—	3·6
174	—	—	—		—	36·78	2·16	—	2·5
175	93·13	2·17	4·70		42·97*	—	—	—	·7
176	91·81	3·99	4·20		23·00	—	—	—	1·7
177	95·68	3·04	·51	·77	31·50	—	—	—	1·0
178	93·72	3·68	2·60		25·54	5·89	15·97	—	1·6
179	89·73	5·71	2·88	1·68	15·71	28·69	2·49	1·37	10·5
180	87·66	6·09	4·38	1·87	14·39	33·14	2·02	1·334	5·2
181	87·87	6·01	4·67	1·45	14·62	35·25	1·84	1·346	5·3
182	88·33	5·79	4·27	1·61	15·26	32·79	2·05	1·313	3·5
183	92·55	4·88	2·57		18·95	14·82	5·75	—	7·2
184	91·26	4·56	4·18		20·0	16·26	5·15	—	7·2
185	92·70	4·44	2·86		20·9	12·96	6·72	—	5·7
186	91·54	4·62	3·84		19·8	14·96	5·69	—	2·2
187	92·52	4·78	2·70		19·4	15·37	5·51	—	12·3
188	89·27	5·60	3·44	1·69	15·93	25·84	2·87	—	4·3
189	89·64	4·37	4·99	1·00	20·51	—	—	—	5·0
190	94·37	3·69	1·94		25·57	—	—	—	1·4
191	93·94	3·77	2·29		24·93	6·10	15·38	—	1·8
192	93·31	3·02	2·52	1·15	30·91	—	—	—	1·5
193	88·12	5·57	6·31		15·82	30·81	2·24	—	2·3
194	87·22	5·49	7·29		15·87	31·26	2·20	—	4·3
195	—	—	—	—	—	15·43	5·48	—	4·4
196	86·38	5·37	6·97	1·28	16·07	—	—	—	1·8
197	—	—	—	—	—	26·93	2·71	—	2·4
198	94·72	3·25	2·03		29·12	4·74	20·1	—	·8

* See footnote on p. 53.

No. on Plates 1 and 3-7.	1-inch map.	Local Name of Vein.	Colliery.	Authority.
199	228	Bonville's Court	- -	C.A.S.
200	228	"	Reynalton -	A.B.C. & C. (Ed. 1907), p. 404
201	230	Little Vein -	LittleVeinSlant, Ammanford	A.B.C. & C. (Ed. 1907), p. 367
202	248	Cae David -	Llynfi - -	Percy, 76, p. 332.
203	247	Four Foot -	Clyne Valley -	A.B.C. & C. (Ed. 1907), p. 383

(1) No. 22.—The figures for Pure Coal, as given in Percy, are incorrect. The figures here given have been obtained by recalculating from "Composition per cent., exclusive of water only."

(2) No. 80.—The analysis here quoted is recalculated from the figures of "Gadly Four-Feet Seam," as given on p. 57 of the second Adm. Rep. under Analysis 1. Analysis 2 adds up to 100·97, thus giving no oxygen in the coal.

(3) No. 85.—See Note to No. 22.

(4) No. 104.—The N, as given on p. 12 of Adm. Rep. 1, should read 1·02 (as on p. 59). The analysis adds up to 100·69, but a note on p. 58 states "The pure coal contained only 3·82 per cent. ash." There is obviously something wrong with the oxygen and ash, but this would

No. on Plates 1 and 3-7.	C.	H.	O.	N.	C/H ratio.	Volatile Matter.	Fuel-ratio.	Sp. Gr.	Ash.
199	93·26	3·28	3·46		28·43	—	—	—	—
200	—	—	—		—	5·89	15·99		1·1
201	94·36	3·63	2·01		26·02	—	—	—	1·5
202	90·78	5·13	4·09		17·69	24·74	3·04	—	5·4
203	88·80	5·36	5·84		16·55	30·30	2·31	—	2·6

not affect the C/H ratio, though rendering the analysis as calculated to "Pure Coal" doubtful.

(5) No. 113.—The figures given represent the mean of two different specimens. The greatest difference on the Pure Coal was ·01 in the C and ·08 in the H. The percentage of ash in both specimens is, however, given.

(6) No. 123.—The analyses as given on pp. 5 and 55 differ in O (9·76 and 9·96). In both cases the analyses add up to over 100 (102·00 and 102·20). As the O is obtained by difference, the figure should read 7·76. This value, therefore, has been taken.

(7) No. 128.—A similar case to No. 113—see note (5).

CHAPTER IV.

ACCURACY OF COAL ANALYSES.

By W. POLLARD.

ALTHOUGH practically every author on the subject of coals and coal-analysis has discussed, or, at any rate, alluded to the question of errors in coal-analysis, it will probably be of assistance if a few examples of possible errors are given before examining the table of analyses. These examples may be thought to be exaggerated, but probably all, and possibly some others not mentioned, will be met with sooner or later whenever a large amount of coal-analysis is done.

1.—PROXIMATE ANALYSIS.

In the proximate analysis of a coal it is important to work as much as possible under constant conditions, and so long as this is done duplicate estimations agree fairly well. If, however, the strength of flame, time of heating, size of crucible, &c., be altered, the results will almost invariably differ, and, unless these details are looked after, will be unreliable. Muck* points out that the addition of powdered quartz to a coal increases the coke, and consequently lowers the volatile matter, so that if two coals are being dealt with whose composition is identical as regards combustible constituents, but which differ in the amount of ash, the proximate analysis will be to some extent misleading.

From some experiments carried out in this laboratory it was found that an increase of water gave an increase in the volatile matter. The following figures illustrate this point. In the first column is the analysis of the original coal, in the second the coal plus an addition of 5 per cent. water, in the third with an addition of 12 per cent. water. The results are calculated to the pure coal (i.e., less moisture and ash).

Volatile matter	37·02	...	37·86	...	38·44
Fixed carbonaceous residue	62·98	...	62·14	...	61·56

The presence in the coal of carbonates also affects the results. In a coal which contained 12 per cent. carbonic acid (present in the coal as carbonate of lime and magnesia), recently analysed in this laboratory, the amount of carbonic acid left in the coke after the estimation of volatile matter was only ·9 per cent., hence 11·1 per cent. had gone off as volatile matter. Further, it is not possible to say to what extent the reaction $CO_2 + C = 2CO$ goes on, but this must have a considerable effect on the result.

Pyrites in the coal must also have some effect, but it is not

* "Chemie d. Steinkohlen," *Bonn*, 1876, p. 16.

easy to judge to what extent. It will be readily seen from the above remarks that the proximate analysis is not sufficiently reliable as a basis for purposes of classification.

2.—Ultimate Analysis.

The way in which moisture is estimated may affect the percentage of practically all the constituents when expressed in percentage of the pure coal. In the following example the difference between moisture obtained by drying in the toluene bath and over sulphuric acid *in vacuo* for 24 hours was ·3 per cent., which would give (according to which is the true figure) the following alternatives:—

	Value of moisture in toluene-bath.	Value of moisture by sulphuric acid in vacuo.
Carbon	81·00	81·00
Hydrogen	4·59	4·56
Oxygen	5·48	5·19
Nitrogen	1·23	1·23
Combustible sulphur	2·18	2·18
Ash	3·35	3·37
Moisture	2·17	2·47
Or calculated to pure coal:—		
Carbon	87·76	88·07
Hydrogen	4·97	4·96
Oxygen	5·94	5·64
Nitrogen	1·33	1·33

It is exceptional to find as big a difference as ·3 per cent. in moisture by the two methods, but where coals rich in moisture are being dealt with it is better to estimate by both methods, as an idea of the possible error in composition is obtained. As already stated, in all coals analysed in this laboratory the figures obtained in the toluene bath have been taken, as that is believed to be the method more generally employed.

Ash.—By ash is meant all non-combustible matter in the coal. The value obtained depends to some extent on how the ash is estimated. For instance, the value for the ash left in the combustion-tube is almost invariably higher than that obtained by ashing in the muffle. The reason appears to be that in the combustion-tube, where the coal is burned in oxygen, more of the sulphur is converted to sulphuric anhydride, which combines with any lime in the ash, whilst in the muffle the atmosphere is less highly oxidising, so that more of the sulphur goes off as a lower oxide, instead of combining with the lime in the ash. The following case supports this view:—

A coal gave 4·80 per cent ash in the muffle and 5·26 in the

combustion-tube. The sulphur in the lower ash was ·11 per cent. in the higher ·30 per cent. If the difference of the two sulphurs (·19 per cent.) be calculated as SO_3, ·47 is obtained, whilst the difference in the two ashes is ·46 per cent.

In every case where the ash has been estimated in both ways the muffle has given the lower result both in ash and sulphur-in-ash. Should minerals containing ferrous compounds be contained in the coal, these will, on combusting the coal in oxygen, become (to a great extent, at any rate) ferric. Hence the ash as found by analysis will be greater than the original ash in the coal, and the oxygen which is obtained by difference will, consequently, be too low. To take a possible case: the composition of a coal as found by analysis is:—

C - - - - - - - - -	83·6
H - - - - - - - - -	4·0
O - - - - - - - - -	1·2
N - - - - - - - - -	1·4
Ash - - - - - - - -	8·6
Moisture - - - - - - -	1·2
	100·00

Supposing that the ash as here found contains 2 per cent. of Fe_2O_3 which was present in the original coal as FeO, the real ash would be represented by 8·6 − 2·0 + FeO, equivalent to 2·0 Fe_2O_3, which is 1·8. Hence true ash is 8·4 instead or 8·6, and the oxygen 1·4 instead of 1·2. Recalculating both to the pure coal (i.e. coal free of water, ash and combustible sulphur), the following figures are obtained:—

	Uncorrected.	Corrected.	Difference.
C - - -	92·69	92·48	·21
H - - -	4·43	4·43	—
O - - -	1·33	1·54	·20
N - - -	1·55	1·55	—
C/H - - -	21·40	21·36	·04

(The above 2 per cent. of Fe_2O_3 represents 23 per cent. of the ash. Cases are given by Percy where 44 per cent. of the ash of a Welsh coal was composed of Fe_2O_3, but it is not possible to say if any of it was present as FeO in the original coal. This error is hardly ever likely to be of serious importance except in coals abnormally rich in ash.)

Pyrites.—We may take next the effect of pyrites. When coal containing this mineral is burned in oxygen, the pyrites is converted into ferric oxide and oxides of sulphur; the latter are absorbed by the lead chromate in the combustion-tube, while the former remains in the boat and is weighed with the rest of the ash.

The pyrites cannot be regarded as part of the organic combustible constituents of the coal any more than the rest of the ash and the moisture, but for every 240 parts of weight of pyrites present in the coal 160 parts of ferric oxide and 128 of sulphur are being counted. The effect of this is that the oxygen, which is obtained by difference, is too low. The following example illustrates this error:—

(All the combustible sulphur has been assumed to be present as pyrites.)

Composition as obtained by analysis.		All S taken as $Fe\,S_2$, and the equivalent $Fe_2\,O_3$ deducted from the ash.		
C	83·65		83·65	
H	4·02		4·02	
O	1·17		2·01	
N	1·45		1·45	
S. combustible	2·23	FeS	4·17	true ash of original coal.
Ash	6·31	Ash less $Fe_2\,O_3$ equiv. to 4·17 FeS_2	3·53	
Moisture	1·17		1·17	

Recalculated on to 'Pure Coal.'			Difference.
C	92·65	91·80	·85
H	4·45	4·41	·04
O	1·30	2·20	·90
N	1·60	1·59	01
C/H ratio	20·8	20·8	—

*Carbonates.**—Carbonates in a coal are more or less decomposed during analysis and give off carbonic acid gas. This is absorbed by the potash-bulbs and is weighed with the carbonic acid formed by the combustion of the carbon of the coal, the result being that the carbon is too high, the true ash too low, and the oxygen too high. When the results of the analysis are calculated on the pure coal all constituents will be affected. In the following example the 6·2 per cent. of ash is assumed to contain 2 per cent. of calcium oxide which was originally present as calcium carbonate. Hence ash less CaO is 4·2 per cent., and CO_2 equivalent to the CaO, 1·57. This makes the ash, plus non-organic constituents, 7·77 instead of 6·2 As in combusting the coal all the CO_2 is assumed to be driven off, the percentage of carbon will be too high by C/CO_2, or 3/11 of 1·57, or ·43 per cent.,

* Cf. Alix and Bay. C.R., vol. cxxxix (1904), p. 215.

and the ash too low by 1·57 per cent., the difference falling on the oxygen. The effect would thus be :—

	Uncorrected.	Corrected.	Difference.
C - -	85·23	84·80	—
H - -	3·64	3·64	—
O - -	1·83	·69	—
N - -	1·29	1·29	—
S combustible	1·81	1·81	—
Ash - -	6·20	7·77	—
or calculated on to pure coal :—			
C - -	92·65	93·79	1·14
H - -	3·96	4·03	·07
O - -	1·98	·76	1·22
N - -	1·41	1·42	·01
C/H ratio -	23·4	23·3	·1

(No notice has been taken of the sulphur in this example, which is only to illustrate the error caused by carbonates).

In practice it has been found that the amount of CO_2 left in the ash varies considerably with each estimation, so that to make the necessary correction the CO_2 has to be estimated specially in the ash left after each combustion. When this is done duplicates agree well.

The next analysis is quoted as showing how the type of coal may be mistaken unless correction is made. It is an extreme case, but one that has actually occurred in the course of coal-analysis in this laboratory. The coal in question was one that had been baked by a whin-sill. It contained 25·2 per cent. of ash and 12·2 per cent. of CO_2, so the true ash (the inorganic or incombustible portion) was 37·4 per cent. The figures give the composition of the pure coal (*i.e.* free from ash, moisture and combustible sulphur), the first column uncorrected, the second the true composition :—

	Uncorrected.	Corrected.	Difference.
C - -	88·69	93·13	4·44
H -	2·80	3·01	·21
O -	7·18	2·44	4·74
N - -	1·33	1·42	·09
C/H ratio -	31·7	30·9	·8

Where both carbonates and pyrites are present there will naturally be complications, as the oxides of sulphur will combine with the lime or magnesia of the carbonates, thus lowering the combustible sulphur and increasing the sulphur-in-ash. It is not possible, however, to correct for this.

Hydrous Minerals.—A possible source of error affecting the hydrogen would be the presence in the ash of minerals containing water of constitution not driven off at 105° C.* As an example (and probably an extreme one) were 5 per cent. of kaolin (which contains about 14 per cent. of water) to be contained in a coal, and were all the water (·7 per cent. on the sample of coal plus ash) driven off and absorbed in the U-tube, the hydrogen would be too high by 1/9th of ·7 per cent. or ·08 per cent. This would give a difference of ·3 to ·5 on the C/H ratio, according to the class of coal. It is hardly likely, however, that a coal would be met with containing so great an amount of hydrous minerals.

Deterioration on Keeping.—The fact that many coals deteriorate, and some are liable to spontaneous combustion when stored has been the subject of a large number of papers. Percy (p. 289–300) goes into this question, quoting the researches of Geinitz Fleck and Hartig,† E. Richters‡ and others, pointing out the fact that it is something besides the pyrites which produces the change. From more recent observations it may even be doubted whether pyrites, except when present in large amount, produces spontaneous combustion. From the discussion on a paper entitled 'On the Prevention of Spontaneous Combustion of Coal at Sea,'§ opinions appear divided, though it seems that whilst pyrites does not fire when pure, it is liable to heat and take fire if mixed with organic matter, as in coal.

Prof. Fischer‖ has published a paper going fully into the question and giving a *résumé* of the older investigations. He tried the effect of bromine on coals and found that both addition and substitution products were formed, the addition products showing the presence of unsaturated compounds. When moist air was passed over powdered coal carbonic acid and water were formed, the coal increasing in weight. If then heated to 120° or 150°C. a loss in weight occurred due to more or less of the carbonic acid and water being driven off. It was found that powdered coal absorbed oxygen more rapidly than lumps, as was to be expected. After a coal had been subjected to this slow oxidation in moist air, it was found to absorb far less bromine than the same sample before oxidation, an additional proof that change in composition had occurred. A test, based on the bromine reaction, is suggested for finding out whether a coal is liable to spontaneous combustion or not. If this test is really satisfactory it should be of considerable value to those who store or transport large quantities of coal.

* Cf. C. von John. *Verh. d. K.K. Geol. Reichsanstalt*, 1904, p. 104.

† "Die Steinkohlen Deutschlands u. a. Laender," 1865, vol. ii, p. 221.

‡ *Dingler*, *Polyt. J.*, vol. cxcv, 1870, p. 315 and 449, vol. cxcvi, p. 317. Also *Wagner's Jahresber.* 1870, vol. xvi, pp. 758-778.

§ T. W. Bunning. *Trans. N. of England Inst. M.E.*, vol. xxv, 1876 p. 107.

‖ *Z. Angew Ch.*, 1899, pp. 564, 764, 787.

The following are, briefly, the conclusions drawn from this paper. Coals contain varying quantities of unsaturated compounds which rapidly absorb oxygen, thereby gaining in weight but deteriorating in coking properties and calorific value. Another series of compounds also occurs which take up oxygen, but give off carbonic acid and water in the process. The latter process, which is usually slow, produces a loss in both the weight and value of the coal. A coal on storing therefore may gain, lose, or remain constant in weight, according to the quantities and relative proportions of the two classes of compounds present, but will almost invariably deteriorate in value. When coals are stored in a cool dry place the alteration is, in most cases, inconsiderable. Moisture certainly assists in the oxidation of the coal. The effect of pyrites on spontaneous combustion is undoubtedly overestimated. The value of ventilating stored coals is doubtful, as although ventilation will help in cooling, it will supply the oxygen necessary to produce combustion.

In connection with the absorption of bromine by coals, it should be mentioned that F. Hart has recently published the results of an investigation on the absorption of iodine, and on the action of sulphuric acid and alcoholic potash or coals. Alcoholic potash extracts a dark substance from caking coals which readily cokes, whilst the coal after this treatment loses its coking properties.*

In order to see to what extent the composition of coals would be affected by keeping, four of the samples stored in this museum were recently re-sampled and analysed afresh, with the following results.

In each case the first column gives the composition of the fresh coal, sampled and analysed soon after it was sent from the pit, the second after it had been stored in a tin-box, the length of time stored being in each case stated. The coals have been stored in the basement of the Jermyn Street Museum, where they were not subjected to great changes of temperature.

Nine-Foot Vein. Anthracite. Stored Four Years.

	Analysis in 1903.	Analysis in 1907.
C - - - - -	93·15	93·13
H - - - - -	3·59	3·52
O - - - - -	1·89	1·99
N - - - - -	1·37	1·36
Sp. Gr. (pure coal)† -	1·396	1·403
C/H ratio - -	25·9	26·5

In this case the change may be taken as *nil*, all variation being within experimental error

* *Chem. Ztg.*, vol. xxx, p. 1204; and vol. xxxi, p. 640.
† See Footnote on next page.

Nine-Foot Vein. Steam Coal. Stored Four Years.

	Analysis in 1903.	Analysis in 1907.
C - - - - -	91·58	91·34
H - - -	4·51	4·42
O - - - - -	2·36	2·67
N - - - - -	1·55	1·57
Sp. Gr. (pure coal)* -	1·316	1·329
C/H ratio - -	20·3	20·7

The variation here is almost within experimental error, but the change, slight as it is, is in the direction to be expected.

Mynyddislwyn Vein. A Bituminous Coal. Stored Four Years.

	Analysis in 1903.	Analysis in 1907.
C - - - - -	86·94	85·55
H - - - - -	5·64	5·43
O - - - - -	5·84	7·27
N - - - - -	1·58	1·75
Sp. Gr. (pure coal)* -	1·290	1·316
C/H ratio - -	15·4	15·8

Top Coal of Rock Vein. A Bituminous Coal. Stored Five Years Seven Months.

	Analysis in 1901.	Analysis in 1907.	Analysis in 1907.
C - - - - - - -	88·30	87·11	87·34
H - - - - - - -	5·45	5.40	5·34
O - - - - - - -	4·83	5·94	5·78
N - - - - - - -	1·42	1·55	1·54
Sp. Gr. (pure coal)* - -	1·272	—	1·299
C/H ratio - - - -	16·2	16·1	16·3

First column, original analysis; second, original fine-ground sample, stored in a bottle all the time; third, original sample stored in a tin box and resampled after the 5½ years.

* The specific gravity of the "pure coal" in the above cases has been obtained by correcting for the specific gravity of the ash as found in each case. (See under Specific Gravity, page 11.)

The difference between the two stored samples may well be only due to experimental error, but with both the bituminous coals the difference between the fresh and the stored samples is marked.

It is noticeable that the anthracite has altered least (if at all), the steam-coal only slightly, whilst the bituminous coals have changed considerably. In each case the change is in the same direction, and though, as already stated, no great accuracy can be claimed for the specific gravity of the pure coal, owing to the possible sources of error discussed on pp. 11 and 29 (to say nothing of the pyrites having partially decomposed in the stored specimen), yet the general indication is that the greater the alteration in the composition the greater the alteration in the specific gravity. The differences are:—

Loss of carbon - -	(·02)	·24	1·39	·96
Gain in specific gravity	(·007)	·013	·026	·020

The change, at any rate in the bituminous coals, is greater than can be reasonably put down to experimental error.

The alteration is similar to that observed by Richters, Fleck Bischoff, and others, and quoted by Percy (p. 289–298), possibly with the exception of specific gravity, as the variation in specific gravity in the examples given by Fleck (*Die Steinkohlen Deutschlands u. andere Laender*, vol. ii., p. 219) is only ·011 in one case and less than ·01 in the rest, although the variation in carbon is greater, and in the cases quoted by Richters,* where some coals showed an increase and some a decrease in specific gravity. Unluckily the specific gravity of the ash is not given, so it is not possible to calculate the results for the pure coal. The great difficulty in commenting on results of this kind is that it is impossible to say whether any constituent remains the same, with possibly the exception of ash, and, as has already been shown, the estimation of ash is at the best of times unsatisfactory. Were the alteration of coals by storage to be at any time reinvestigated, it would be well to take a pound or two of the finely ground sample and thoroughly mix with it, say, 1 per cent. of some inert and easily and accurately estimated substance (*e.g.* gold-dust), then divide up into lots to be periodically examined. There would then be one constant from which to calculate the changes that had occurred.

The following is a summary of the approximate errors so far considered:—

* *Dinglers Polyt. J.*, vol. cxcvi (1870), p. 321.

	C per cent.	H per cent.	O per cent.	N per cent.	C/H ratio.
Ferrous minerals in ash	·2	—	·2	—	·1
Pyrites	85	·05	·90	·01	—
Carbonates	1·14	·07	1·22	·01	·1
Ditto in extreme case	4·4	·2	4·7	·1	·8
Hydrous minerals	—	·1	—	—	? ·4
Maximum observed alteration in four Welsh coals after storage	1·39	·21	1·43	·17	·51

No great accuracy is claimed for these figures, they are only intended to show in what direction, and approximately to what extent, the composition of a coal may be affected.

CHAPTER V.

Comparison of Different Bands of the Same Seam and Comparison of Different Samples from the Same Seam in the Same Locality.

By W. Pollard.

After considering the possible analytical errors the following questions arise:—What variation is met with in the composition of—

1. Coal in different parts of the same seam (i.e., top, middle, and bottom coals).
2. Different samples from the same seam and pit.

Unluckily there are only six cases under heading 1 available. These are given in the following table:—

Analysis No.	C %	H %	O & N %	C/H ratio.
61. (Nos. 118, 119, 120 of Percy)				
Top Coal - - - - -	91·63	4·98	3·39	18·4
Middle Coal - - - -	92·45	4·89	2·66	18·9
Bottom Coal - - - -	91·30	4·72	3·98	19·3
152. Top Coal - - - - -	92·65	4·45	2·90	20·8
153. Middle Coal - - - -	90·58	4·33	5·09	20·9
154. Bottom Coal - - - -	91·49	4·45	4·06	20·6
155. Top Coal - - - - -	90·91	4·79	4·30	19·0
156. Middle Coal - - -	88·64	4·72	6·64	18·8
157. Bottom Coal - - - -	89·98	4·82	5·20	18·7
158. Top Coal - - - - -	92·40	4·38	3·22	21·1
159. Middle Coal - - - -	91·36	4·32	4·32	21·2
160. Bottom Coal - - - -	90·48	4·34	5·18	20·9
183. Top Coal - - - - -	92·55	4·88	2·57	18·9
184. Middle Coal - - - -	91·26	4·56	4·18	20·0
185. Bottom Coal - - - -	92·70	4·44	2·86	20·9
186. Top Coal - - - - -	91·54	4·62	3·84	19·8
187. Bottom Coal - - - -	92·52	4·78	2·70	19·4

Under the second heading twenty cases occur, in some of which there are more than two analyses from the same locality available. These are given in the following pages.

Vein.	C%	H%	O & N%	C/H ratio.	Fuel-ratio.
Black [or Ras-las] - -	88·66	4·89	6·45	18·1	2·25
" " - -	86·85	4·77	8·38	18·2	—
Difference - -	1·81	·12	1·93	·1	—
Black [or Ras-las] - -	88·24	5·24	6·52	16·8	1·91
" " - -	90·74	4·84	4·42	18·7	—
" " - -	90·45	5·28	4·27	17·1	—
Maximum difference	2·50*	·44	2·25*	1·9	—
Black [or Ras-las] - -	87·49	5·33	7·18	16·4	1·74
" " - -	89·27	5·60	5·13	15·9	2·87
Difference - -	1·78	·27	2·05	·5	1·13
Big [probably above the Ras-las]	93·77	3·74	2·49	25·1	14·46
" " -	93·63	3·70	2·67	25·3	—
" " -	93·99	3·76	2·25	25·0	—
" " -	93·87	3·76	2·37	25·0	13·87
Maximum difference	·36	·06	·42	·3	·59
Big [or Ras-las] - -	93·56	3·57	2·87	26·2	15·95
" " - -	93·21	3·57	3·22	26·1	10·76
" " - -	92·46	3·20	4·34	28·9	—
Maximum difference	1·10	·37	1·47	2·8	5·19
Four Foot [of Clyne Valley]	88·80	5·36	5·84	16·6	2·31
" " -	88·51	5·02	6·47	17·6	2·56
Difference - -	·29	·34	·63	1·0	·25
Big [or Ras-las] - -	93·87	3·59	2·54	26·2	22·8
" " - -	93·97	3·50	2·53	26·9	16·2
" " - -	94·49	3·67	1·84	25·8	—
Maximum difference	·62	·17	·70	1·1	6·6

* Greatest difference observed in this Table.

Vein.	C°/o	H°/o	O & N°/o	C/H ratio.	Fuel-ratio.
Big [or Ras-las] - - " " - -	93·91 93·16	3·70 3·52	2·39 3·32	25·4 26·4	15·4 —
Difference - -	·75	·18	·93	1·0	—
Little [or Brass] - - " " - -	94·19 94·36	3·58 3·63	2·23 2·01	26·3 26·0	18·5 —
Difference - -	·17	·05	·22	·3	—
Peacock [or Brass] - - " " - -	93·39 93·80	3·66 3·16	2·95 3·04	25·5 29·6	18·0 —
Difference - -	·41	·50	·09	4·1*	—
Rock Vawr [No. 2 Rhondda] - " " -	85·23 84·78	4·80 5·57	9·97 9·65	17·8 15·2	1·46 1·31
Difference - -	·45	·77	·32	2·6	·15
No. 2 Rhondda - -	91·78 91·66	5·13 4·85	3·19 3·49	17·9 18·9	4·47 4·12
Difference - -	·12	·28	·30	1·0	·35
Three Quarter [of Monmouthshire] - " " -	87·81 89·64	5·09 4·37	7·10 5·99	17·3 20·5	2·09 —
Difference - -	1·83	·72	1·11	3·2	—
Graigola - - - - " - - - -	92·73 91·70	4·64 4·80	2·63 3·50	20·0 19·1	— 5·37
Difference - -	1·03	·16	·97	·9	—

* Greatest difference observed in this Table.

Vein	C°/o	H°/o	O & N°/o	C/H ratio.	Fuel ratio.
Big [of Monmouthshire]	89·65	4·37	5·98	20·5	—
„ „ -	90·58	5·39	4·03	16·8	—
Difference - -	·93	1·02*	1·95	3·7	-
Tregloin - - -	93·79	3·67	2·54	25·6	17·8
„ - - -	93·78	3·59	2·63	26·1	17·1
Difference - -	·01	·08	·09	·5	·7
Red [of the Neath Valley]	93·26	3·89	2·85	24·0	12·6
„ „ -	92·74	3·96	3·30	23·4	12·9
„ „ -	92·48	4·03	3·49	23·0	15·6
Maximum difference	·78	·14	·64	1·0	3·0
Red [of the Neath Valley]	93·56	3·48	2·96	26·9	—
„ „ -	93·42	3·39	3·19	27·5	10·1
Difference - -	·14	·09	·23	·6	—
Red [of the Neath Valley]	93·32	3·84	2·84	24·3	14·6
„ „ -	94·08	3·79	2·13	24·9	14·4
Difference - -	·76	·05	·71	·6	·2
Red [of the Neath Valley]	93·02	4·27	2·71	21·8	12·7
„ „	92·58	3·91	3·50	23·7	12·0
Difference - -	·44	·36	·79	1·9	·7

* Greatest difference observed in this Table.

The greatest differences observed in the two cases are therefore:—

(1) Different parts of the same vein:—

	C °/o	H °/o	O & N °/o	C/H ratio
Maximum difference - -	2·27	·44	2·34	2·0
Mean of max. differences -	1·67	·19	1·76	·7

(2) In same vein and pit but different samples and sometimes different analysts :—

	C °/o	H °/o	O & N °/o	C/H ratio
Maximum difference - -	2·50	1·02	2·25	4·1
Mean of max. differences -	·81	·31	·89	1·46

From the above data it will be seen that it is impossible to lay down on a map the composition of the coals with minute accuracy, and that the exact limits of anthracite, steam-, and house-coals is still indefinite, from a chemical point of view. It is quite possible that some of the early analyses may be inaccurate, for when charcoal-furnaces only were available for making combustions, the labour and difficulties must have been great. It should also be borne in mind that, in many cases, no details as to the collection of the samples are available, so that it is possible that the analyses in some cases represent a part of the vein only, and not the average composition of the whole thickness.

CHAPTER VI.

Comparison of Different Seams in the Same Locality.

By W. Pollard.

It is frequently the case that the lower the vein, in geological sequence, the more anthracitic it is. This rule, if proved to be universally correct, would be a point in favour of anthracitisation having been due to a cause operating from beneath. Also it should be possible, if the composition of the upper veins were known, to predict what the approximate composition of the lower veins would be. To test these points the following table of analyses of different veins from the same pits has been prepared, giving the approximate distance between veins, composition of the pure coal, C/H ratio, and fuel-ratio.

Vein.	Distance between veins in yards.	C %	H %	O & N %	C/H ratio.	Fuel-ratio
Charcoal - -		84·56	6·57	8·87	12·9	2·10
	174					
Black - - -		87·49	5·33	7·18	16·4	1·74
		89·27	5·60	5·13	15·9	2·87
Four Foot - -		93·69	3·74	2·57	25·1	13·9
	47					
Big - - -		93·16	3·52	3·32	26·4	—
		93·91	3·70	2·39	25·4	15·4
	21					
Peacock - -		94·02	3·96	2·30	23·7	12·9
Four Foot - -		93·77	4·64	1·59	20·2	7·92
„ Dyffryn -		92·93	4·91	2·16	18·9	5·16
	54 to 70					
Nine Foot - -		91·89	4·59	3·54	20·0	6·03
Red - - -		87·77	4·97	7·26	17·7	2·22
	17					
Three Quarter -		86·63	5·13	8·24	16·9	1·95
	20					
Rock - - -		88·30	5·45	6·25	16·2	1·77
		88·61	5·29	6·10	16·8	2·03
	50					
Old - -		87·93	5·30	6·77	16·6	2·18
Graig - - -		92·57	4·72	2·71	19·6	5·12
	151 to 210					
Two Foot Nine -		94·11	4·19	1·70	22·5	8·06
	12 to 22					
Four Foot - -		92·74	3·96	3·30	23·4	8·75

Vein.	Distance between veins in yards.	C °/o	H°/o	O & N °/o	C/H ratio.	Fuel-ratio.
Big or Stanllyd -		94·21	3·75	2·04	25·1	16·4
		93·82	3·81	2·37	24·6	16·2
		93·13	2·17	4·70	43·0*	—
	35					
Peacock - -		93·67	3·73	2·60	25·1	16·1
	48					
Middle - -		94·31	3·64	2·05	25·9	18·1
	17					
Lower - - -		94·09	3·58	2·33	26·3	18·5
Elled - - -		84·42	5·48	10·10	15·4	—
	5 to 11					
Big - - -		87·14	6·49	6·37	13·4	—
	8 to 12					
(Top of) Three Quarter		89·81	5·11	5·08	17·6	2·99
Three Quarter -		86·25	5·90	7·85	14·6	—
	83 to 99					
Old - - -		90·74	5·23	4·03	17·4	3·40
No. 2 Rhondda -		93·58	4·05	2·37	23·1	12·1
	70					
Lower - - -		93·71	3·69	2·60	25·4	12·4
Four Foot - -		88·51	5·02	6·47	17·6	2·56
		88·80	5·36	5·84	16·6	2·30
	12					
Yankee - -		88·12	5·57	6·31	15·8	2·24
	10					
Yard - - -		87·22	5·49	7·29	15·9	2·20
Upper Four Foot -		90·92	4·51	4·57	20·2	—
	64 to 71					
Ras-las - -		90·87	4·65	4·48	19·5	—
Graig - - -		91·66	4·71	3·63	19·5	4·10
	151 to 210					
Two Foot Nine -		93·35	4·15	2·50	22.5	7·96
	12 to 22					
Four Foot - -		91·86	3·93	4·21	23·4	8·42
	23 to 35					
Six Foot - -		92·73	3·95	3·32	23·5	7·31
Big - - -		93·17	2·12	4·71	43·9*	—
	35					
Peacock - -		93·94	3·77	2·29	24·9	15·4

* See Note on p. 53.

Vein.	Distance between veins in yards.	C °/o	H°/o	O & N °/o	C/H ratio.	Fuel-ratio.
Six Foot - -	49	93·63	4·01	2·36	23·4	
Nine Foot - -		92·65	3·96	3·39	23·4	10·7
Red - - -	332	93·03	3·51	3·46	26·5	11·9
Big - - -	20 to 35	93·92	3·55	2·53	26·5	19·0
		94·49	3·67	1·84	25·8	
Brass - - -		93·39	3·66	2·95	25·5	18·0
		93·80	3·16	3·04	29·6	
Big - - -	21	93·37	3·43	3·20	27·2	17·5
Brass - - -		93·70	3·90	2·40	24·0	14·8
Big - - -	5 to 14	87·81	5·12	7·07	17·2	2·03
Three Quarter -	54 to 59	87·20	5·10	7·70	17·1	2·05
Meadow - -		87·16	5·42	7·42	16·1	1·95
Yard - -	39	90·53	4·98	4·49	18·2	3·32
Cae David - -	146	87·99	5·64	6·37	15·6	1·91
		90·78	5·13	4·09	17·7	3·04
Duffryn - -	20	89·75	4·92	5·33	18·2	3·29
Lower Six Foot -	38 to 43	91·25	4·84	3·91	18·9	3·96
Nine Foot - -		91·37	4·93	3·70	18·5	3·99
Four Foot - -	73	85·20	5·40	9·40	15·8	2·27
Nine Foot - -	59	86·30	5·34	8·35	16·2	2·29
Cribbwr - -		87·50	5·15	7·35	17·0	2·46
Penyfilia or Five Foot	141	91·66	4·87	3·47	18·8	4·32
		88·66	6·03	5·31	14·7	2·84
Six Foot - -	13	90·75	4·73	4·52	19·2	3·93
Three Foot - -		91·46	5·02	3·49	18·2	4·08

Vein.	Distance between veins in yards.	C°/o	H°/o	O & N °/o	C/H ratio.	Fuel ratio.
Forest - - -	5 to 8	86·38	5·37	8·25	16·1	
No. 3 Rhondda -		88·44	5·32	6·24	16·6	2·94
Wernffraith - -	199 to 256	92·45	4·80	2·75	19·3	
Graigola - -		92·73	4·64	2·63	20·0	
		91·70	4·80	3·50	19·1	5·37
Red - - -	333	92·48	4·03	3·49	23·0	15·6
Big - - -		93·96	3·74	2·30	25·1	17·2
Eighteen Foot -	9 to 16	93·52	3·82	2·62	24·5	13·3
Cornish - -	30 to 35	93·83	3·95	2·22	23·8	13·8
Nine Foot - -		93·79	3·86	2·35	24·3	15·0
Big - - -	5	90·58	5·39	4·03	16·8	
Three Quarter -	30	87·81	5·09	7·10	17·2	2·09
		89·64	4·37	5·99	20·5	
Black - - -		88·24	5·24	6·52	16·8	1·91
		90·74	4·84	4·42	18·7	
Lower Trichwart -	about 17	94·1	3·6	2·3	26·1	18·6
Lower Pumpquart		93·00	3·68	3·32	25·3	18·3
Drap - - -	83	92·59	4·54	2·87	20·4	
Green - - -	26	93·98	3·88	2·14	24·2	13·9
Big - - -		93·83	3·74	2·43	25·1	13·9
		93·77	3·74	2·49	25·1	14·5
Slatog - - -	36 to 38	83·63	5·28	11·09	15·8	1·80
Curly - - -	14 to 17	85·93	5·92	8·15	14·5	1·65
Bodor - - -	17 to 18	85·69	5·81	8·50	14·7	1·97
Hughes - -		77·40	4·67	17·93	16·6	·94

Vein.	Distance between veins in yards.	C°/o	H°/o	O & N °/o	C/H ratio.	Fuel ratio.
Big - - - -	21	95·15	2·11	2·74	45·1*	
Peacock - -		93·73	3·22	3·05	29·1	
Ward's Fiery -	220	94·68	4·23	1·09	22·4	
Graigola - -		90·14	5·03	4·83	17·9	3·82
Four Foot - -	120	92·03	4·70	3·27	19·6	5·60
Five Foot - -		92·17	4·63	3·20	20·0	5·87
Four Foot - -	44	91·81	3·99	4·20	23·0	
Big - - -		93·88	3·65	2·47	25·7	

* See Note on p. 53.

On going through this Table it will be seen that approximately in about half the cases the lower the vein the higher the carbon. Of the remainder several show the reverse, while in others the carbon varies irregularly. The same result approximately is observed in the carbon-hydrogen ratio.

The only chance of ascertaining exactly how far the rule holds good, and what the rate of variation is, would be to have a larger number of specimens analysed than have been available up to the present.

CHAPTER VII.

Classification of Coals.

By W. Pollard.

The more recent papers on this subject are:—

C. A. Seyler, 'Chemical Classification of Coal,' *Proc. S. Wales Inst. Eng.*, Vol. XXI, p. 483, and Vol. XXII, p. 112.

'Report on the Operation of the Coal Testing Plant of the U.S. Geol. Survey,' *Professional Papers*, No. 48, Part I., p. 156.

S. W. Parr, 'The Classification of Coals,' *J. Am. Chem. Soc.*, Vol. XXVIII, 1906, p. 1425, and *Colliery Guardian*, Vol. XCII, 1906, p. 1209.

F. F. Grout, 'The Composition of Coals,' *Economic Geology*, Vol. II, 1907, p. 225.

The Pennsylvania System (Fuel Ratio) will be found in Report M.M. of the second geological survey of Pennsylvania.

In Mr. Seyler's paper, on pp. 483-491, a good résumé of the older classifications is given. His own classification, though not perfect, is one of the best, if not the best, so far available. It is based on the percentage of hydrogen and carbon, calculated on the pure coal. The hydrogen determines the genus and the carbon the species. The following table, taken from 'Analyses of British Coals and Coke' (p. xv), gives the system:—

Seyler's Classification of Coal.

Carbon.	Anthracitic.	Carbonaceous.	Bituminous.			Lignitious.	
	—	—	Meta-	Ortho-	Para-	Meta-	Ortho-
	Carbon over 93·3 per cent.	93·3—91·2	91·2—89·0	89·0—87·0	87·0—84·0	84—80	80—75
Per-bituminous Genus Hydrogen over 5·8 per cent.	—	—	Per-bituminous (Per-meta-bituminous)	Per-bituminous (Per-ortho-bituminous)	Per-bituminous (Per-para-bituminous)	Per-lignitious	
Bituminous Genus Hydrogen 5·0—5·8 per cent.	—	(Pseudo-bituminous species)	Meta-bituminous	Ortho-bituminous	Para-bituminous	Lignitious. (Meta)	(Ortho)
Semi-bituminous Genus Hydrogen 4·5—5·0 per cent.	—	Semi-bituminous species (Ortho-semi-bituminous)	Sub-bituminous (Sub-meta-bituminous)	Sub-bituminous (Sub-ortho-bituminous)	Sub-bituminous (Sub-para-bituminous)	Sub-lignitious (Meta)	(Ortho)
Carbonaceous Genus Hydrogen 4·0 — 4·5 per cent.	Semi-anthracitic species.	Carbonaceous species (Ortho-carbonaceous)	Pseudo-carbonaceous (Sub-meta-bituminous)	Pseudo-carbonaceous (Sub-ortho-bituminous)	Pseudo-carbonaceous (Sub-para-bituminous)	—	—
Anthracitic Genus Hydrogen under 4 per cent.	Ortho-anthracite	Pseudo-anthracite (Sub-carbonaceous)	Pseudo-anthracite (Sub-meta-bituminous)	Pseudo-anthracite (Sub-ortho-bituminous)	Pseudo-anthracite (Sub-para-bituminous)	—	--

N.B.—The various genera are arranged in Column 1 vertically according to the hydrogen. The species in each genus are arranged horizontally according to the carbon.

The United States Geological Survey have recently dealt with methods of classification of coals, but do not mention Mr. Seyler's paper. The classification finally adopted by them is founded on the proportion of carbon to hydrogen, and the limits proposed for the different classes of coal are as follows* :—

		C/H ratio.
A	Graphite - - - - - - - - -	∞ to ?
B	Anthracite - - - - - -	? to ?30
C		?30 to ?26
D	Semi-anthracite - - - - - -	?26 to ?23
E	Semi-bituminous - - - - - -	?23 to 20
F	Bituminous - - - - - -	20 to 17
G		17 to 14·4
H		14·4 to 12·5
I		12·5 to 11·2
J	Lignite - - - - - - - -	11·2 to ?9·3
K	Peat - - - - - - - -	?9·3 to ?
L	Wood (cellulose) - - - - - -	7·2

* This system has also been discussed by B. Renault, 'Sur quelques Micro-organismes des Combustibles fossiles.' *Bulletin de la Soc. de l'Industrie Minérale.* Sér. 3, t. xiii, 1899, and t. xiv, 1900. Also separately published.

The classification founded on the fuel-ratio, that is, on the relation of coke to volatile matter on coal free from water and ash, as adopted by the Pennsylvania Geological Survey, may be summarised as follows:—

	Fuel-ratio.
Anthracite - - - - - - - -	12 and over
Semi-anthracite - - - - - - -	8 to 12
Semi-bituminous - - - - - - -	5 to 8
Bituminous - - - - - - - -	0 to 5

This system has been found to be unsatisfactory, except for the anthracitic and semi-anthracitic coals.

Prof. Parr has recently proposed a classification, based on the factor $VC \times \frac{100}{C}$, where VC represents the volatile carbon unassociated with hydrogen, and C the total carbon in the coal. In the bituminous and lignitious classes "inert volatile" (volatile matter less volatile carbon) is made use of for the purpose of further discrimination. In the following table the proposed limits are given:—

	$VC \times \frac{100}{C}$	Inert Volatile.
Anthracite - - -	4 and under	—
Semi-anthracite - -	4 to 8	—
Semi-bituminous - -	10 to 15	—
Bituminous A - - -	20 to 32	5 to 10
B - -	20 to 27	10 to 15
C - - -	32 to 44	5 to 10
D - - -	27 to 44	10 to 15
Black Lignite - - -	27 and over	16 to 20
Brown Lignite - - -	27 and over	20 to 30

A further suggestion is made to express "Intrinsic Value" or "Relative Merit" of coals as fuel, assuming the true fuel-value of a coal to depend on the total carbon, available hydrogen and sulphur. The method is best shown by an example, for a coal composed of

Carbon - - - - - -	78·31	per cent.
Hydrogen - - - - - -	4·31	"
Sulphur - - - - - -	·90	"
	83·52	

Hence the "Gross Coal Index" is $\frac{100}{\cdot 8352}$ or 120. This means that with this coal 120 lbs. will be required to make 100 lbs. of actual fuel.

Apparently the most recent classification is that of Professor Grout. It may be briefly stated to be based on fixed carbon for the anthracites to semi-bituminous, and on fixed carbon and total carbon for the bituminous and lignitious coals. Apart from a suggested diagrammatic representation of coals, the following table shows the classification proposed. All data are calculated on coal free from ash and water :—

	Fixed Carbon.	Total Carbon.
Graphite - - - - - -	over 99	—
Anthracite - - - -	over 93	—
Semi-anthracite - - -	83 to 93	—
Semi-bituminous - - -	73 to 83	—
High grade bituminous - -	48 to 73	82 to 88
Low grade bituminous - -	48 to 73	76·2 to 82
Cannel - - - - - -	35 to 48	76·2 to 88
Black Lignite - - - - -	35 to 60	73·6 to 76·2
Brown Lignite - - - - -	30 to 55	65 to 73·6
Peat and Turf - - - - -	below 55	below 65
Wood - - - - - -	—	—

The data on which the various classifications here mentioned are based are therefore:—

(1) Percentage of carbon and hydrogen, calculated on pure coal.

(2) The relative proportion of carbon to hydrogen—that is, the C/H ratio.

(3) The relative proportion of coke to volatile matter—that is, the fuel-ratio.

(4) Volatile carbon $\times \frac{100}{\text{total carbon}}$ ith due consideration of "inert volatile."

(5) Fixed carbon with due consideration of total carbon in pure coal.

Before comparing the value of these classifications for the present purpose it should be stated that the following remarks apply only from the anthracite to the bituminous or per-bituminous coals, as lignites do not occur in this coalfield, although in one or two cases coals nearing the lignitious class have been met with.

The volatile matter and fixed carbon estimations have already been shown to be liable to considerable errors, so neither of these figures should be taken for purposes of classification if better are available. Mr. Seyler has shown also that the hydrogen and volatile matter are closely connected, so that any system in which volatile matter, and hence coke, are made use of, together with total carbon, practically amounts to classifying on carbon and hydrogen. And as carbon and hydrogen can be estimated with great accuracy, it seems more rational to use them as a basis in classification, although the proximate analysis of a coal is, in most cases, sufficient to discriminate between anthracite, semi-anthracite, and semi-bituminous coals.

The choice of classification for the present purpose therefore lies between Mr. Seyler's and the carbon-hydrogen ratio. As the object in view is to show the progressive change in character of the coal in this coal-field, and as this is most obviously shown by figures on a map, the preference falls to the C/H ratio. This ratio has the disadvantage that there is necessarily a certain amount of overlapping in the various groups and species, but it has the advantage of combining the two constituents, which can be simultaneously and directly estimated with a considerable degree of accuracy, and of avoiding the necessity of recalculating on to the pure coal, when, as has been shown, considerable errors may be introduced through the oxygen having to be taken as the difference of the sum of all other constituents and 100. The only serious causes of error likely to occur in the C/H ratio are the presence of carbonates or hydrous minerals in the coal, both of which would probably be observed and the carbonate, at any rate, corrected for. The C/H limits as proposed by the United States Geological Survey would require to be modified for this coal-field, as there are, for example, many good anthracites with a C/H ratio of less than 26. The limits as marked on the maps do not designate a hard and fast line, and are not intended to imply, for instance, that all coals on one side of, say, a line marked 23 are anthracites, whilst all those on the other are semi-anthracites, &c., but are only intended to illustrate the general distribution of the different classes of coal.

In the following table the C/H limits theoretically possible for the various coals of Mr. Seyler's classification are given, also the limits observed for the various analyses here published, arranged on the same classification.

All available ultimate analyses have been made use of, provided locality and vein could be identified, as it appeared fairer to do this than to select analyses. In a few cases where an ultimate analysis was not available the proximate has been given. Where there appears reason to think an analysis is doubtful or does not represent a fair sample of the vein, attention is drawn to the fact in a footnote.

Anthracitic Genus.

Species.		Possible limits of C/H ratio.	Observed limits.	No. of cases.
Ortho-anthracite		23·3 and over	23·7 & over	54
Pseudo-Anthracite	Sub-carbonaceous	22·8 and over	23 to 29·9*	17
	Sub-metabituminous	22·25 and over	None observed	
	Sub-orthobituminous	21·75 and over	22·08	1
	Sub-parabituminous	21·0 and over	None observed	
	Sub-metalignitious	20·0 and over		
	Sub-ortholignitious	18·75 and over		

Carbonaceous Genus.

Semi-anthracitic	20·7 — 24 ?	21·3 to 23·35	9
Ortho-carbonaceous	20·3 — 23·3	20·6 to 23·0	10
Sub-metabituminous	19·7 — 22·8	20·5 to 20·9	3
Sub-orthobituminous	19·3 — 22·2	20·31	1
Sub-parabituminous	18·7 — 21·75	None observed	
Sub-metalignitious	21·0 — 17·8		
Sub-ortholignitious	16·6 — 20·0		

Semi-bituminous Genus.

(Anthracitic)	18·7 — 21·2 ?	20·2	1
Ortho-semibituminous	18·2 — 20·7	18·4 to 20·4	25
Sub-metabituminous	17·8 — 20·3	18·2 to 20·2	8
Sub-orthobituminous	17·4 — 19·7	17·7 to 18·8	3
Sub-parabituminous	16·8 — 19·3	17·8 to 18·2	2
Sub-metalignitious	16·0 — 18·7	None observed	
Sub-ortholignitious	15·0 — 17·8	16·6	1

* Two cases are not included here (Nos. 167 and 175) as the hydrogen appears abnormally low, namely 2·12 and 2·17 per cent. With the exception of No. 169, in which the percentage of hydrogen is 2·11, no other coals, even in Pembrokeshire, show less than 3·0 per cent. of hydrogen. The C/H ratios are respectively, 43·8, 43·0 and 45·1. Had they contained 3 per cent. of hydrogen the C/H ratios would have been 31·0, 31·0 and 31·7. They were communicated in MS., so it is possible a copying mistake was made, or they may have been selected for some purpose or investigation unknown.

Bituminous Genus.

(Anthracitic)	16·1 — 19·0 ?	17·6	1
Pseudo-bituminous	15·7 — 18·6	17·4 to 18·2	3
Meta-bituminous	15·3 — 18·2	15·7 to 17·9	8
Ortho-bituminous	15·0 — 17·8	15·2 to 17·6	21
Para-bituminous	14·5 — 17·4	15·4 to 16·9	8
Meta-lignitious	13·8 — 16·8	15·2 to 15·8	2
Ortho-lignitious	12·9 — 16·0	14·6	1

Per-bituminous Genus.

(Anthracitic)-	13·9 ? — 16·2 ?	None observed	
(Carbonaceous)	16·1 and less		
Per-metabituminous	15·7 and less	13·4	1
Per-orthobituminous	15·3 and less	13·4 to 14·7	5
Per-parabituminous	15·0 and less	12·9 to 14·7	4
Per-metalignitious	14·5 and less	None observed	
Per-ortholignitious	13·8 and less		

Summary of observed limits for the various Genera.

Anthracitic genus	22 and over	
		Overlap 1·35*
Carbonaceous genus	20·3 — 23·35	
		Overlap ·1
Semi-bituminous genus	16·6 — 20·4	
		Overlap 1·6
Bituminous genus	14·6 — 18·2	
		Overlap ·1
Per-bituminous genus	12·9 — 14·7	

* For example, a coal with C/H ratio between 22 and 23·35 might belong to either the anthracitic or carbonaceous genus.

Out of the 203 analyses available 12 are only proximate analyses, so it is impossible to name these on Seyler's or the C/H classifications. Of the 191 where it is possible to name on these classifications, the C/H ratio shows, on the limits adopted by the United States Geological Survey:—

Anthracites	33
Semi-anthracites	42
Semi-bituminous	29
Bituminous I.	44
Bituminous II.	38
Bituminous III.	5

CHAPTER VIII.

Explanation of the Iso-anthracitic Charts (Plates 3 to 7).

By A. Strahan.

The object of these charts is to show areas of equal anthracitism in each seam or group of seams. The positions of the samples on the analyses of which the charts are founded are indicated by numbers corresponding to those in the table on pp. 14-27.

The degree of anthracitism of each sample is expressed by the factor representing the relation of carbon to hydrogen, i.e. the C/H ratio, that factor being more suitable for the purpose than any other, for the reasons explained on p. 52. The figures in the table which give that relation range from 13 to more than 31, and for convenience the lines corresponding to the numbers 14, 17, 20, 23, 26, and 29 have been selected for illustration of the iso-anthracitic areas on the charts. The iso-anthracitic line 17, for example, is drawn through all those localities in which it is calculated that the C/H ratio would equal 17.

The space between lines 14 and 17, in any one seam, may be regarded as corresponding to the area in which that seam has the character of house-coal, but begins to assume that of steam-coal, that is belongs to the Bituminous Genus of the Table on p. 54; while that between lines 17 and 20 includes the passage into steam-coal, and steam-coal, that is the Semi-bituminous Genus of the Table. Lines 20 to 23 include steam-coal of the Carbonaceous Genus. Line 23 marks the oncoming of anthracites, and from line 24 (not shown on the charts) upwards the coals may be regarded as true anthracites.

The iso-anthracitic lines have, of course, no relation to the outcrops of the seams. In fact, a line is sometimes continued a little beyond the area in which the seam to which it relates exists, or even beyond the margin of the coal-field, where the evidence obtainable in the coal-field suffices to indicate the position it occupied before the coal-field was reduced to its present dimensions by denudation.

Plate 3.

The chart forming this plate is founded upon analyses of the lowest veins, namely, those which occur below the datum-line of Plate 2. Taken from east to west, the group includes the following seams :—

Old Coal.	Middle Vein.
Meadow Vein.	Lower Vein.
Cribbwr Vein.	Trigloin Vein.
Four Feet Vein (Morfa).	Lower Pumpquart Vein.
Four Feet Vein (Clyne Valley).	Lower Trichwart Vein.
Yankee Vein.	Lower Level Vein.
Three Feet Vein (Clyne Valley).	Timber Vein.
Brass or Peacock Vein.	

The samples for analysis were obtainable from the margin only of the coal-field, none of the veins being accessible at present in the interior. The seams as a group lie on the same horizon, near the base of the Coal Measures, and are included in a thickness of about 500 feet of measures. The Timber Vein may correspond to the Stanllyd, which is taken as the datum-line in Plate 2.

The iso-anthracitic line 17 is determined by the analyses of the Old Coal and Meadow Vein towards the east, and by analyses of the Cribbwr Vein and the Clyne Valley coals in the South Crop. The direction in which the anthracitic character develops is foreshadowed by the analyses of both the Old and the Meadow seams, but evidence of the position of line 20 is wanting. The position of line 23 is indicated by analyses of the Brass Vein, and those of lines 26 and 29 are fixed by a series of analyses of the Brass, Trigloin, Middle, Lower, Lower Trichwart, and Lower Pumpquart Veins. The Pembrokeshire analyses lie near, or on the higher side of, line 29, and correspond to, or slightly surpass, the highest stage of anthracitism reached in Carmarthenshire.

Plate 4.

This chart is founded on analyses of the vein which, in different parts of the coal-field, passes under the following names:—The Black or Rock (eastern part), Ras-las or Nine Feet (East Glamorganshire), Nine Feet or Big (North Crop on the borders of Glamorganshire and Brecknock), probably the Stanllyd and Carway Big (Carmarthenshire), and possibly the Timber Vein (Pembrokeshire). This coal-seam being more widely recognisable than most others, has been selected as the datum-line in Plate 2, and is more fully illustrated than the rest in the analyses.

The iso-anthracitic line 17 is well determined in Monmouthshire, but, so far as regards the South Crop, is founded only on an analysis of the Nine Feet at Morfa (No. 27), of the Nine Feet at Llynfi (No. 23), and of the Nine Feet at locality No. 9. It coincides approximately with the line 17 in the underlying seams (Plate 3).

The iso-anthracitic line 20 follows a parallel course, but is bent north-westwards to accommodate an analysis of the Ras-las at Dowlais (No. 22), quoted by Dr. Percy. Not improbably this bend would disappear, or be modified, if further analyses east of locality 22 were available.

Line 23, so far as it is determined by analyses of the Nine Feet at Hirwain (No. 24) and the Nine Feet of locality 19, follows a normal course, but its westward continuation is not proved.

Line 26 is founded on a series of analyses of the Big, Nine Feet, or Stanllyd Vein of the anthracitic region. The bend in it may be due partly to experimental error in analysis, and have little significance.

Line 29 is not reached in the Big or Stanllyd in Carmarthenshire, but its position is indicated by analysis No. 13, and it is

touched at Hook (No. 198) in the Timber Vein, which may correspond to the Stanllyd.

The Green and Drap Veins, which lie 25 and 107 yards respectively above the Big Vein, are also shown upon this chart. In the Green Vein the positions of lines 23 and 26 are determined at localities 190 and 146, and that of line 20 in the Drap Vein at locality 145. The lines 20 in the Drap, 23 in the Green, and 25 in the Big Vein (Nos. 12, 144) approximately coincide, while line 26 in the Green lies a mile north of line 26 in the Big Vein. This, of course, means that in any one vertical section the Drap would be more bituminous than the Green and the Green than the Big, in accordance with the rule mentioned on p. 2. But, on the other hand, on comparing Plate 4 with Plate 3, we find that the line 23 in the Big or Nine Feet Vein lies six miles south of the line 23 in the Brass Vein, which is about 20 yards below, and again that the line 26 in the Big or Nine Feet lies distinctly south of the line 26 in the lower veins. This means that the Big in any one vertical section would be more anthracitic than some of the seams below it. The rule referred to is therefore not universally true.

Plate 5.

A group of veins which lies not far above the datum-line of Plate 2, and includes the Red, Elled, Big and Three Quarters of Monmouthshire, is illustrated in Plate 5.

In the Three Quarters, or lowest vein of the group, the iso-anthracitic line 17 is founded on several analyses, and is not far from coinciding with the line 17 in the Black or Ras-las Vein, thirty yards below (Plate 4). An analysis, however, at Blaina (No. 92), on the authority of Dr. Percy, gives a carbon-hydrogen factor of 14·6, which indicates that the coal becomes more bituminous in a north-westerly direction. Taken by itself, this exception to the rule that the seams become more anthracitic towards the north-west might not have had much significance, but it acquires importance when taken in connection with the analyses of the Red, Elled and Big, the overlying members of this same group of seams.

The Red, Elled and Big Veins are illustrated on the same plate. In these veins the position of the line 14 is determined by two analyses, both quoted from Dr. Percy, one being the Big Vein of Blaina (No. 29) and the other the Elled Vein of Blaina (No. 90). The line 17 as determined in those veins coincides approximately with the line 17 in the Three Quarters, and though the lines 14 do not coincide they agree in showing that the upper as well as the lower vein of the group becomes more anthracitic eastwards and southwards. This exception to the rule appears to be local and confined to this group of seams.

Plate 5 also illustrates what is sometimes known as the Aberdare series of seams. This series includes the Two Feet Nine, the Upper Four Feet and the Six Feet. Further west some seams well known in the Vale of Neath occupy about the same horizon. As shown in Plate 2 these Aberdare and Vale of Neath coals

correspond collectively to the Monmouthshire group illustrated in Plate 5, though the correlation of individual seams is open to doubt. The iso-anthracitic line 17 in the Aberdare Four Feet seam is determined by an analysis (No. 87) of a sample from the Ebbw Vale Iron Works, quoted from the Admiralty Report. It lies a short distance only from the line 14 in the Elled and Big Veins as shown on the same plate. The anthracitic character, however, increases westwards in the Upper Four Feet, for a number of analyses extending from Dowlais to near Maesteg fixes the position of line 20 at a distance of about 8 miles west of line 17. The loop in the line 20 is drawn to accommodate a single analysis (No. 88) of coal from Hill's Plymouth Merthyr quoted in the Admiralty Report and giving a carbon-hydrogen ratio of 22·1.

The Aberdare Six Feet Vein lies below the Four Feet and should, at any one spot, be more anthracitic; accordingly the line 20 in the Six Feet runs about 2 miles south and west of the line 20 in the Four Feet. The lines 23 in the two seams coincide, but in the Two Feet Nine seam, which lies above the Four Feet, we have to travel a mile and a half further on before we reach the anthracitic degree represented by line 23. These facts are in accordance with the rule that the lower seams are the first to become anthracitic.

Three lines are shown in the Vale of Neath seams. They are founded on analyses of the Four Feet and of the Eighteen Feet, which lies 10 to 14 yards above the Four Feet seam. Both coals are placed on the market as anthracites, this part of the Vale of Neath being commonly regarded as lying on the margin of the anthracitic region.

The evidence furnished independently by these seams indicates that the iso-anthracitic lines trend north-westwards, as though there were a local anthracitic centre near Glyn Neath. This trend is not observable in the underlying seams (Plates 3 and 4), but is maintained in an overlying seam, the Red Vein, which is also shown on Plate 5. Though there is no doubt that further analyses would show that the lines soon resume their normal westerly trend, yet this agreement in an unusual direction in so many veins, taken as they were independently, is too pronounced to be ignored. It indicates that there are local peculiarities in the distribution of the anthracitic character in certain seams or groups of seams, which are difficult to explain on the supposition that the seams were originally alike, but were subsequently anthracitised by one common cause.

The Red Vein here referred to is not to be confused with the Red Vein of Ebbw Vale (compare Sections 7 and 10 in Plate 2). It is recognised as a workable seam from the Dulais, a tributary of the Neath, to near Ammanford, and is regarded as an anthracite, but as approaching a steam-coal in places. The analyses enable the iso-anthracitic lines 23 and 26 to be fixed with some precision from Dillwyn in the Dulais valley to Cawdor, Cwmamman.

On comparing the Red Vein with those below it, it will be

seen that the line 26 in the Red Vein approximately coincides with the line 23 in the Eighteen Feet Vein, and is south of the line 23 in the Cornish Vein. This indicates that the Red Vein becomes anthracitic in a region where the veins several hundred feet below it have not yet assumed that character. Here again we have an exception to the rule that the lower seams are the earlier to become anthracitic, and a further illustration of the fact that some seams have a certain individuality in their behaviour as regards their assumption of the anthracitic character.

A single analysis (No. 124) of the Lower or Welsh Vein of Cwm Clic, quoted from Percy, has been inserted in this chart. The carbon-hydrogen ratio is 25·4, which indicates that the seam is more anthracitic than the Red Vein, though it lies above it. Confirmation of this is desirable.

The Drap and Green Veins lie above the supposed equivalent of the Nine Feet, and therefore correspond approximately in position to the Vale of Neath and Aberdare seams illustrated in the plate. Their composition confirms the supposition previously mentioned, that the normal trend of the iso-anthracitic lines is soon resumed west of the Vale of Neath.

Plate 6.

Plate 6 shows the iso-anthracitic lines in the seam known in different areas as the Tillery or Red Ash, the Rock-fawr, the Brithdir, the Pen-y-graig or No. 2 Rhondda. It may be compared with the chart of the Ras-las Vein in Plate 4. In both the anthracitic character develops steadily north-westwards, and, except for irregularities in the curves, which are drawn to suit certain analyses, and which might be modified if the series of analyses were more complete, there is a fairly close coincidence of lines 14, 17 and 20 in the higher seam with lines 17, 20 and 23 in the lower seam. This relation of the lines gives data for calculating the vertical rate of decrease of anthracitisation for certain localities. Thus in Monmouthshire a decrease of 3 (from 20 to 17) in the carbon-hydrogen ratio occurs in a vertical distance of 852 feet, giving a rate of 1 in 284 feet. But near locality No. 179 in the Brithdir, and locality No. 7 in the Ras-las Vein, the vertical distance is 1,350 feet, and the decrease of 3 (from 23 to 20) in that distance gives a rate of 1 in 450 feet. Again at Bronbil (locality Nos. 55 and 59) the mean of two Admiralty analyses gives a carbon-hydrogen ratio of 16·9 in the higher vein, while at Morfa (locality No. 27) the ratio is 16·2 in the Nine Feet Vein, about 2,600 feet below the Bronbil seam. Here, therefore, the higher and the lower seams are about equally bituminous, a state of affairs which probably prevails throughout the extreme southern margin of the coal-field.

The analysis of the No. 2 Rhondda Vein which lies nearest to

the anthracitic region is quoted from Percy, who gives the seam as the Upper or Pen-y-graig Vein of Cwm Clic. It fixes one point on the line 23, but leaves us in doubt whether that line takes the north-westward trend which is observable in the Red and other veins of Plate 5. It proves, however, that the No. 2 Rhondda seam reaches the anthracitic degree indicated by the line 23 further south than do either the Red or the Cornish Four Feet Veins, and thus furnishes another exception to the rule that the lower seams are the more anthracitic. So far as this locality is concerned the rule is generally reversed.

On Plate 6 an analysis of No. 3 Rhondda Seam also is entered. It indicates that at Penrhiw (localities Nos. 125, 196) that seam is slightly less bituminous than the Forest Vein which lies about 77 yards above it. In the Graig Seam, of which we have two analyses, the line 20 agrees closely with the line 20 in the No. 2 Rhondda Seam, although the Graig Seam lies upwards of 150 yards below the No. 2 seam.

The Hughes Vein, which is also illustrated on Plate 6, forms the lowest and most important member of a group which includes also the Slatog, Curly, and Rotten or Bodwr Veins, and has been extensively worked from near Glyn Corwg to the western end of Gower. It lies from 450 to 500 yards above the No. 2 Rhondda Seam or its local equivalent.

A comparison of the lines in the Hughes Vein with those of the No. 2 Rhondda Seam shows that the line 20 in the Hughes would, if prolonged, join line 20 in the No. 2 Rhondda, but that line 17 lies much closer to line 20 in the Hughes group than it does in the No. 2 Seam farther east. This implies that the change in character is more rapid in the west, a conclusion of which we shall obtain further evidence.

Plate 7.

The Mynyddislwyn, or Bedwas Vein, is well known as a house coal in Monmouthshire, but the analyses are too few to admit of more than an approximate determination of line 14. That line lies generally nearer the anthracitic region than does line 14 in the No. 2 Rhondda Vein (Plate 6), as was to be expected but apparently a local reversal of the rule occurs at locality 72. There the carbon-hydrogen ratio in the Mynyddislwyn Vein is 15·4, whereas in locality No. 123 the ratio in the Charcoal Vein, the supposed equivalent of No. 2 Rhondda, is only 12.9, according to the Admiralty Report.

As already explained, the Wernffraith, or Swansea Four Feet Vein, is taken to be the equivalent of the Mynyddislwyn Vein in preference to the Graigola, or Six Feet Vein, which lies 250 yards below the Four Feet. The analyses enable us to trace the line 20 for some miles. It follows the same general direction as line 20 in the Six Feet Vein, but runs into it, and crosses it to the

west, the evidence for this being an analysis of Ward's Fiery Vein* (No. 104) quoted in the Admiralty Report.

That analysis gives a carbon-hydrogen ratio of 22·4, as compared with 17·9 in the Llanelly Fiery (No. 105) to the west of it, and with 19·1 in that vein (No. 101) to the east of it, although Ward's Fiery Vein lies 218 yards above the Llanelly Fiery Vein. The exact position, however, of line 20 towards the west must in any case be regarded as doubtful, inasmuch as it is founded on one analysis only.

The Graigola, or Six Feet Vein, is 270 to 350 yards above the Hughes Vein. The iso-anthracitic line 20, as determined by several analyses of the Graigola Vein, runs slightly north of the line 20 in the Hughes Vein for part of its course, and turns northwards towards the east so as to suggest the existence of a local anthracitic centre between Swansea Vale and Pontardulais. Combining this chart with that of the Aberdare Four Feet (Plate 5), we obtain the relative positions of two local anthracitic centres with a comparatively bituminous area extending northwards between them. Our information does not suffice to prove that either vein would show both centres, but it is likely that the Aberdare Four Feet would do so, for the north-westerly trend of the lines shown in Plate 5 is certainly replaced by a westerly or south-westerly trend a little further west.

An analysis (No. 122) of the Swansea Three Feet Vein is entered on this same chart. That vein lies 13 yards below the Six Feet, but appears to be slightly more bituminous than it, on comparison of analyses Nos. 100 and 122.

The Swansea Five Feet lies between the Four Feet and Graigola (Six Feet) Veins, and 140 yards above the latter. The analyses are limited to a small area: two from the same colliery give a carbon-hydrogen ratio of 18·8 in the Five Feet Vein (No. 74) as compared with 19·18 in the Graigola (No. 100), which gives a vertical decrease of ·38 in 140 yards in the carbon-hydrogen ratio, or 1 in about 1,000 feet. The position of line 23 is indicated by one analysis only (No. 76). The iso-anthracitic lines in the Five Feet Vein are not inserted on the plate for want of space.

The rate at which the bituminous character decreases northwards has been determined with great accuracy in one locality in this vein. Three sets of samples (Nos. 152—160) were collected with this object in view from three spots situated in a line running nearly north and south. Locality A (Plate 8), which yielded the samples 158, 159, and 160, was 520 yards

* The Fiery Vein of Llanelly is well known to correspond to the Graigola or Swansea Six Feet, but "Ward's Fiery Vein" is the name given on old plans to the Llanelly, or Box Big Vein, which corresponds to the Swansea Four Feet. The Fiery Vein of Oldcastle (Analysis No. 105), on the other hand, must be the Llanelly Fiery, inasmuch as the Llanelly Six Feet, or Box Big Vein, is "in the wind" at that colliery.

N. 11° W. of Locality B, which yielded the samples 152, 153, 154; Locality B was 1,310 yards N. 22° E. of Locality C which yielded the samples 155, 156, 157. The results are shown in the following table and in Plate 8:—

Swansea Five Feet Vein.

	Locality A. Carbon-hydrogen ratio.	Locality B. Carbon-hydrogen ratio.	Locality C. Carbon-hydrogen. ratio.
Top Coal -	21·10	20·81	18·98
Middle Coal -	21·15	20·89	18·77
Bottom Coal -	20·85	20·58	18·67
Mean - -	21·03	20·76	18·807

These figures show that the change becomes more gradual as true anthracite is approached. Thus from C to B the rate on the mean values is one unit of the carbon-hydrogen ratio gained in 604 yards, while from B to A the rate is one unit in 1,813 yards.

The change in the part of the coal-field from which these samples (Nos. 152—160) are taken is certainly more rapid than it is in the eastern part, but data for an exact comparison are lacking, no other opportunity having occurred of obtaining samples from the same vein at a series of suitable spots.

CHAPTER IX.

ORIGIN OF ANTHRACITE.

By A. STRAHAN.

MUSHET was the first to attempt an explanation of the variations in the composition of Welsh coals. He pointed out that coals of different qualities are associated with similar strata, that the coal only, and not the accompanying measures, is changed, and that there is no contact of trap-rocks to account for the phenomena. He found difficulty in the supposed growth of a wide variety of plants in a limited space, and concluded that "fermentation and the degree of temperature thereby excited during the period of transition—but not that of submersion—from wood or vegetable matter into coal, may . . . furnish the most rational clue to the mystery."*

De la Beche also sketched generally the distribution of anthracite, and wrote: "Taking the coal measures of South Wales and Monmouthshire, we have a series of accumulations in which the coal beds become not only more anthracitic towards the west, but also exhibit this change in a plane which may be considered as dipping to the S.S.E. at a moderate angle, the amount of which is not yet clearly ascertained, so that in the natural section afforded we have bituminous coals in the high grounds and anthracitic coals beneath."

He found nothing to lead him to infer that there was any original difference in the coal, and attributed the anthracitisation to subsequent change. The change he believed to be due to the volatile compounds formed by decomposition having carried off relatively greater proportions of the hydrogen and oxygen than of the carbon. The view that it was due to disturbance of the strata was, in his opinion, untenable, inasmuch as the Coal Measures at Merthyr Tydfil were not more disturbed than they were at Pontypool, nor at Hirwain than they were at Pyle. The bituminous coal of Vobster, moreover, near the Mendip Hills, was far more contorted than a great proportion of the anthracitic coal of South Wales. He concludes by referring to long-continued high temperature as capable of effecting the change, and points out that if a portion of the coal-area was depressed below the other parts, and thus brought more within the influence of internal heat, decomposition in that part might have proceeded faster than in other parts. The fact that the lower beds were more anthracitic than the upper beds pointed to an influence acting from beneath and not from above.†

* 'Papers on Iron and Steel,' London, 1840.

† *Memoirs of the Geol. Survey*, vol. i., pp. 217 to 221, 1846.

In 1859 Dr. J. P. Bevan* described the distribution of anthracitic and bituminous coals, and attributed the anthracitisation to "trap-rocks far below the surface, which have never appeared." The alteration was believed by him to have been effected before the "Upper Measure Coals" were deposited.

Mr. Thomas Joseph,† in 1870, classified the coals according to their behaviour when burning, and showed on a map the distribution of the various classes in the eastern part of the coal-field. The gradual progress of the change from east to west was clearly recognised, but, in addition, certain faults were credited with throwing in a higher stage of anthracitisation. Mr. Joseph noted also "the regular gradation of change upwards from the lowest to the highest seams." He concluded that the coals had originally been bituminous or "dark-smoky," and had been subsequently altered, the measure for the change being marked by the progressive development of "slip cleavage" in the coal-seams. The change was attributed to magnetic or galvano-magnetic action, and was considered to have been long posterior to "the occurrence of faults."

In 1877 Mr. E. T. Hardman‡ attributed the anthracitisation to internal heat, caused by intrusion of plutonic rocks. Prof. Galloway,§ in 1884, classed the coals as "long-flaming *dry* coal above; the caking coals in the middle; and the *dry* steam, or anthracitic, coals at the bottom." The loss of bituminous matter was attributed to the seams having been covered by a greater thickness of strata, and consequently exposed to a higher temperature in the anthracitic region than elsewhere.

In 1900 Mr. C. A. Seyler‖ published the results of a large number of analyses and discussed in great detail the classification of coals, but did not touch upon the causes of anthracitisation.

In 1903 Mr. John Roberts**, in evidence given before the Royal Commission on Coal Supplies, described the distribution of bituminous, semi-bituminous, and anthracitic coals in South Wales, and estimated the area occupied by each class.

Mr. David Burns†† discusses various objections to the theories in which anthracite is supposed to have resulted from the loss of volatile matter in a bituminous coal, and comments on the fact that in going from coking coal to anthracite there is a diminution of ash. He suggests that chlorine disengaged by volcanic

* *The Geologist*, vol. ii, p. 75, 1859.

† *Trans. S. Wales Inst. Eng.*, vol. vii, p. 137, 1872.

‡ *Journ. Roy. Geol. Soc. Ireland*, New Series, vol. iv, p. 200, 1877.

§ *Trans. Cardiff Nat. Soc.*, vol. xvi, p. 20, 1885; and 'Course of Lectures on Mining. Pub. by the *S. Wales Inst. Eng.*, Cardiff, 1900.

‖ *Proc. S. Wales Inst. Eng.*, vol. xxi, p. 483, 1898–1900, and vol. xxii, p. 112. See also 'Analyses of British Coals and Coke,' Introduction, *Coll. Guardian*, 1907, and 'Practical Coal Mining,' vol. i, p. 67, London, 1907.

** *Roy. Com. on Coal Supplies*, 2nd Rep., 1904, p. 302, and Plates 21, 22, 23.

†† *Trans. N. of England Inst. M.E.*, vol. liv, 1904, Appendix 4, p. 1.

action combined with the hydrogen of the bituminous coal, while part of the hydrogen combined with the oxygen of the coal to form water. The free hydrochloric acid thus formed carried with it some portion of the ash as chlorides. This hypothesis is not well supported by evidence.

There was thus a general agreement that the anthracitic character had resulted from a change effected upon coals which had been originally bituminous. Three explanations of the change had been put forward, namely, that the anthracitic seams had been more deeply buried and consequently exposed to a higher temperature, that they had been altered by the neighbourhood of plutonic rocks, and lastly, that they were more affected by slip-cleavage.

To all of these theories serious objections present themselves. In the part of the coal-field where the measures are thickest, and where the seams were most deeply buried in Carboniferous times, the coals are bituminous. The same remark applies also to the covering of Secondary rocks which was subsequently spread over them. That covering was thickest in the southern and bituminous region where part of it still survives, and thinnest, if indeed it extended at all, over the northern and anthracitic part.

The trap-rocks of Pembrokeshire, which were appealed to as showing the probability of similar molten masses having penetrated under parts of the coal-field, are of pre-Carboniferous age, and therefore can have had no effect upon the Coal Measures. Moreover, coals, where whin-sills have come into contact with them in other coal-fields, have been coked and not anthracitised, while at the same time the percentage of ash has largely increased.

Slip-cleavage is not developed in anthracitic seams, nor does the theory that anthracitisation is due to the escape of volatile matter accord with the fact that the lower seams are generally the more anthracitic.

The hypothesis that the anthracitisation was due to disturbance of the strata was put aside in consideration of the facts mentioned by De la Beche, and in view also of the distribution of anthracite in Ireland and elsewhere.

In taking the view that the differences between the anthracitic and bituminous coals of South Wales are mainly due to original differences in composition we are guided by the following considerations:—

1. While the charts confirm the general conclusions which have long been held on the distribution of the various classes of coal, they show further that some seams, or some groups of seams, possess a certain individuality. In some there are local anthracitic areas of which no evidence appears in others; the rate also at which the change to anthracite takes place differs in different seams. From a combination of these causes the rule that every seam is more anthracitic than the one above it is by no means universally true. Again, not only do certain seams differ from those above and below them, but bands in the same

seam may show considerable differences in composition. These characters lend no support to a theory of the seams having been altered by one common cause acting subsequently to their deposition, such, for example, as regional metamorphism.

2. The iso-anthracitic lines show no definite connection with the faults and disturbances. The dislocations of the strata in South Wales fall into three systems:—

(*a*) The nearly east and-west disturbances which traverse Somerset, Devon, and the south of Ireland, involving within their northern margin the Vale of Glamorgan, Gower, and South Pembrokeshire.

(*b*) The west-south-west system which runs for the most part north of the coal-field, but branches of which traverse the Vale of Neath, the valley of the Tawe and part of the anthracitic region.

(*c*) The faults which range across the coal-field with directions ranging from south to south-south-east.

Of these three systems the east-and-west (*a*) and the west-south-west (*b*) are similiar in their characters. Both affect broad belts of country, and are accompanied by sharp folding and over-thrusting, yet one of them (*a*) traverses part of the coal-field where the seams are bituminous, though they may be vertical or even inverted, and sharply folded, as in Gower. That the other (*b*) traverses the anthracitic region appears therefore to be an accidental coincidence, though the fact that the most easterly appearance of a west-south-west disturbance in the Vale of Neath agrees in position with the on-coming of the anthracitic character, was at first sight strongly suggestive of a connection between the two.

The north-and-south faults (*c*) have a local effect upon the quality of the coal. The nature of the alteration is not brought out in any of the analyses quoted in this volume, the object of which is to show the normal quality of the coal, but is reported to consist in the loss of bituminous matter. The fact, however, that the iso-anthracitic lines run approximately at right angles to the faults sufficiently disproves any connection between the two. Moreover, the north-and-south faults are neither so large nor so numerous in the anthracitic parts as in some of the bituminous parts of the coal-field.

The north-and-south faults sometimes throw into opposition coals of different degrees of anthracitisation. The vertical displacement effected by these faults often amounts to 200 yards, and in exceptional cases to 800 yards. The seams now brought face to face were, therefore, originally separated by a thickness of strata equal to the throw of the fault, and differ in accordance with the general rule that the lower seams are the more anthracitic. No example has come to light of the same seam permanently changing in degree of anthracitisation on the opposite sides of a fault. It is to be inferred from these facts that the anthracitisation was prior to the faulting.

3. The anthracitisation is obviously not connected with the existing outlines of the coal-field, as determined by denudation. The anthracitic region appears to have lain principally outside

the north-western margin of the main coal-field and to the west of it, in Pembrokeshire. Most of it has been removed by denudation, but so far as the surviving part of it enables us to judge it must have extended in a direction slightly south of west. The form of the iso-anthracitic lines suggest that it never extended eastwards beyond Monmouthshire, if so far; its westward limit is, of course, unknown. Again, there is no connection between anthracitisation and depth from the present surface. Slight changes in the quality of the coals are observable at their outcrops, but it has not been proved that these changes are in the direction of anthracitisation. On the other hand, in the bituminous region the coals continues to be bituminous so far down as they have been followed, while in the anthracitic region the coals are anthracitic up to their outcrops.

It appears, therefore, that the coals had assumed their present character before either the outlines or the surface-configuration of the coal-field had been determined by denudation.

4. A feature in the anthracites which is brought out by the collation of analyses consists in their freedom from ash as compared with the bituminous coals. The fact is important from the point of view of the origin of anthracite, for obviously the alteration of a bituminous coal into an anthracite by the loss of bituminous matter from any cause would increase the percentage of ash.

The comparative freedom of anthracite from ash has long been known, and has been alluded to by several writers. The fact is brought out by Mushet's analyses,* and is commented on by Richardson.† Mushet's analyses are proximate only, and therefore do not yield data for the C/H ratio. On classifying them according to the fuel-ratio, we find that the average percentage of ash ranges from 3·43 in 96 analyses of bituminous coals, to 3·66 in 56 analyses of semi-bituminous, 2·61 in 25 analyses of semi-anthracite, and 2·50 in 16 analyses of anthracite. That fuel-ratio is not the best basis of classification has already been shown (p. 50), but it suffices to distinguish roughly the four classes named. Melly‡ gives as one of the distinctive features of anthracite a low percentage of sulphur and ash. Mr. David Burns also calls special attention to the small proportion of ash in anthracite.§

By ash is meant all the incombustible residue. This includes not only any slaty films which are too thin to be picked out from the coal, but all pyrites, sulphates, and carbonates which line cracks in the coal, or are disseminated through the coal, as well as the inorganic material contained in the tissues of the plants which formed the coal. In the analyses quoted on pages 14-16 no attempt has been made to discriminate between these different sources of ash, and it is questionable whether much

* 'Papers on Iron and Steel,' by David Mushet. London, 1840.

† *Proc. Inst. C.E.*, vol. viii, 1849, p. 98.

‡ *Trans. N. of England Inst. M.E.*, vol. xxx, 1882, p. 175.

§ *Trans. N. of England Inst. M.E.*, vol. liv, 1904, Appendix 4, p. 1.

would be gained by doing so. The minerals which line cracks in the coal are as likely as not to have been derived from the coal itself, and, at any rate, to separate them out before analysis would give a wrong idea of the coal as it is put on the market. The sulphur, moreover, could never be completely eliminated, as was shewn by Percy in 1875†. The presence of alumina in the ash would seem at first sight to prove that the ash was partly of sedimentary origin. But it has been shown to be "a characteristic and abundant constituent of the ash of many, if not of all, the species of terrestrial Lycopodia; . . . that it is present in notable quantity in at least one species of tree-fern though practically absent in others; and that it occurs in insignificant amount . . . in almost every plant in which its presence has been carefully sought for."* For these reasons we will take the analyses in their original forms in considering the distribution of ash, remarking merely that the great differences of ash in some of the coals, and especially in those of the bituminous part of the coal-field, may be partly due to other causes than difference in the original composition of the coals themselves. Our conclusions must be formed on averages rather than on individual samples.

For the purposes of this inquiry we can use only those seams or groups of seams which can be traced through both the bituminous and the anthracitic areas. Of these the most prominent is the Ras-las and its supposed equivalents. The seams below the Ras-las persist as a group, though they are not traceable individually. The following diagrams (Plate 9) show the result of plotting a curve to represent the percentage of ash in the Ras-las and underlying seams, the analyses being arranged in the order of the carbon-hydrogen ratio. The anthracites occupy about the left half of the table, the right half showing the steam- and house-coals. In the third diagram the curve has been partly smoothed by taking the mean of all analyses which fall between two adjoining units in the carbon-hydrogen ratio. Thus the mean in the column 25-24 is obtained by combining analyses Nos. 31, 25, 191, 161, 52. On the other hand, in each of the columns 24, 23 and 22, 21, only one analysis was available. The violent zigzags in this part of the line may be due, therefore, to the approximation to the truth being less close than where the mean could be taken of a number of analyses. The same remarks apply to the column 15-14.

Except for these imperfectly proved parts, the line of means in diagram 3 forms a fairly steady gradient from about 1 per cent. of ash at the anthracitic end, to about 4 per cent. or more at the bituminous end of the scale. A larger number of analyses would probably still further smooth the gradient, but even as it stands it proves the general rule that ash diminishes with anthracitisation. In connection with this may be taken the fact that the anthracitic coals are more often "solid" than the

† 'Metallurgy,' p. 568.

* A. H. Church, *Proc. Roy. Soc.*, vol. xliv, 1883, p. 127.

bituminous seams. Figures for an exact comparison are not easy to obtain, but probably the comparison of a large number of average sections of seams in the two ends of the coal-field would show that the bituminous coals are more apt to be split up by partings of sedimentary material than the anthracitic. Freedom from partings and, to the eye, an almost perfect homogeneity are familiar characters in anthracitic seams. The seams themselves also are probably on the average rather thinner.

In order to ascertain what percentage of ash is contained in a mass of miscellaneous plants, and what is the nature of the alteration effected by spontaneous heat, two samples of meadow hay from the same rick were obtained through the kindness of Messrs. Dumbelton, the one coming from near the outside, where comparatively little heating had gone on, the other from the centre of the rick, where the hay had been much heated and had become almost black. As the difference in moisture in the two samples was considerable, both were dried at 105° C. before analysis. The analyses were carried out exactly as for a coal, and the results obtained were:—

Proximate Analysis.

	Light (outside) sample.	Dark (heated) sample.
Volatile matter - - - -	76·69	69·41
Fixed carbonaceous residue - -	15·70	21·31
Ash - - - - - - - -	7·61	9·28

Ultimate Analysis.

Carbon - - - - - - -	45·23	46·82
Hydrogen - - - - - - -	5·85	5·33
Oxygen - - - - - - -	39·18	36·75
Nitrogen - - - - - - -	2·13	1·82
Ash - - - - - - -	7·61	9·28

or calculated on "ash-free" sample:—

Proximate Analysis.

Volatile matter - - - - -	83·00	76·51
Fixed carbonaceous residue - -	17·00	23·49

Ultimate Analysis.

Carbon - - - - - - -	48·96	51·61
Hydrogen - - - - - - -	6·33	5·88
Oxygen - - - - -	42·41	40·50
Nitrogen - - - - -	2·30	2·01

It will be noted that the percentage of ash in the light (outside) sample is 7·61 and in the dark (heated) sample 9·28. Presumably the greater part of this ash was contained in the

plants. Further, the net result of the alteration by heating was to diminish the percentage of hydrogen, oxygen, and nitrogen, and thereby increase the percentage of carbon and ash.

The foregoing statements may be summed up as follows :—

1. The seams are not all similarly anthracitic, and though each seam is generally more anthracitic than the one above it, there are many exceptions to this rule.

2. The anthracitic character was not due to faults, but existed before the faults were formed.

3. The anthracite existed as such before the coal-field was reduced by denudation to its present dimensions.

4. The percentage of ash diminishes *pari passu* with the decrease of bituminous matter.

These conclusions point to the variations in the composition of the coals having been either original or at least of very early date. For the disturbances of the strata and the denudation which brought the coal-field to its present shape, were both in the main accomplished before Triassic times. The differences between the coals therefore already existed before any of the Secondary rocks were laid down. Further than this the evidence derived from the distribution of anthracite does not carry us, but the remaining arguments point to the date of anthracitisation having been contemporaneous with the deposition of the Coal Measures—the strongest being that which is derived from the variation in the percentage of ash, for it is obvious that the variation cannot be due to subsequent alteration.

A further argument may be derived from the existence of pebbles or fragments of coal in some of the conglomeratic bands which occur not infrequently in the Pennant Grit of South Wales and in other coal-fields. As pointed out by M. Renault,* these coal-fragments are enclosed in bands of sandstone or argillaceous sandstone. They sometimes have the fracture of ordinary coal, with alternate bright and dull layers, and are angular; or again, some have been rounded into true pebbles. They have not been deformed by the pressure of the sandstone which envelops them, nor have they shrunk since they were enveloped. It is to be inferred, therefore, that they were derived from some pre-existing coal-seam, and had already acquired their hardness and definite volume when they were buried in the sand—that is to say, they had passed into the condition of coal while the Coal Measures were still in process of deposition.

In seeking to account for an original difference in the composition of coals, it seemed worth while to inquire whether there was any connection between it and the distribution of the Coal Measures before they were curtailed by denudation. No part of the original margin of the Coal Measures has survived, except possibly in parts of Pembrokeshire, but there is sufficient evidence to enable us to sketch its position approximately.

The evidence commences in the Lower Carboniferous rocks.

* 'Sur quelques Micro-organismes des Combustibles Fossiles,' *Bull. de la Soc. de l'Industrie Minérale*, sér. 3, t. xii, 1899, and t. xiv, 1900. Also separately published.

The limestone-series is well developed in South Pembrokeshire, but dwindles away rapidly and is actually overlapped by Millstone Grit towards the north. Throughout the main coal-field the northward attenuation is no less marked, as is proved not only by a comparison of the relative thicknesses on the north and south crops, but by the poor development in the outlier of Pen Cerig-calch. Lastly, at the north-east corner of the coal-field the whole limestone-series does not exceed 100 feet in thickness, as compared with about 500 feet further south. Traced in an east-and-west direction the thicknesses are relatively more constant, with a general tendency, however, towards expansion in the south-westerly region of the coal-field.

Assuming that the northward attenuation continued in the tract from which the Carboniferous rocks have been denuded, the original margin of those rocks must have lain not far away from, and appears to have run approximately parallel to, the present margin of the coal-field.

The position of the original margin of the Coal Measures is more problematical, for by analogy with other regions they may be assumed to have overlapped the Lower Carboniferous rocks, and to have extended still farther north. Moreover, their margin probably occupied positions successively farther north as the subsidence which led to the deposition of so huge a mass of sediment progressed. The reasoning, however, which has been applied in the case of the underlying rocks gives a somewhat similar result.

The varying thicknesses of the Lower Coal Series, which alone of the subdivisions of the Coal Measures has a sufficiently wide distribution for our present purpose, is shown in Plate 9. The Lower Coal Series extends from the No. 2 Rhondda Seam (or its equivalents) down to the Farewell Rock or top of the Millstone Grit. Most of the measurements are taken from shaft-sections published in Vert. Sects. of the Geological Survey, Sheets 80, 81, 83, 84, and 85. But few, if any, of the shafts have reached the Farewell Rock, and several have not been carried down to the lowest coals; in such cases an addition has been made for the estimated thickness of the unproved strata.

The smallest development is found at the east end of the coal-field, where the Lower Coal Series is 625 feet thick. The maximum increase takes place thence in a direction rather north of west, a thickness of 1,710 feet and 1,747 feet being reached in a distance of 12 miles. In the next 4 or 5 miles, however, there is a considerable drop, for in the Rhondda valleys the thickness averages about 1,430 feet. West of these valleys expansion sets in again and continues to the end of the coal-field.

The expansion, however, is more rapid along the South Crop than along the North Crop, so that a considerable difference between the two sides of the coal-field develops westward. The greater thickness of the measures of the South Crop is partly illustrated in Plate 2, in which Sections 3, 4, and 7 represent the North Crop, while Sections 2, 5, and 6 represent the South Crop. The direction of maximum thickening is somewhat west of south

in the western part of the coal-field as compared with somewhat north of west in the eastern part.

Assuming as before that attenuation marks an approach to an original shore-line, this map suggests that the original margin of the Coal Measures also may have been roughly parallel to the present margin of the coal-field, but that it curved southwards at the eastern end. There appears to have been an area of least subsidence somewhere to the east of the coal-field, possibly in the neighbourhood of the post-Carboniferous anticline which brings up Silurian rocks in the Usk inlier.

A comparison of this map with the charts showing the iso-anthracitic lines lends no support to the suggestion that the distribution of anthracite had any connection with the position of the shore-line. It is true that in the western end of the coal-field the anthracitic character increases as the thickness of measures decreases, and again in the eastern end the group of seams illustrated on Plate 5 loses bituminous matter towards the region where the measures are thinnest. But, on the other hand, it is obvious that the anthracitic area is far from coinciding with the region of smallest thickness. On the contrary, the smallest thickness in the south-east and the greatest thickness in the south-west are both associated with bituminous coals.

Moreover, it is not the case in other parts of the kingdom that anthracite is associated with marginal deposits, South Staffordshire and the Forest of Wyre being notable examples. It appears, therefore, that though the anthracitic region of South Wales may have been nearer the original margin than much of the bituminous region, that circumstance does not account for the difference in the coals.

Though we can offer no explanation of the distribution of the anthracite, we may point out that coals are known to vary in character both according to the kind of vegetable remains, and according to the parts of the plants of which they are formed. That, again, the preservation of the vegetable mass varied according to the local circumstances, such as the distance it was drifted, the depth of water in which it was submerged, the length of time that elapsed before it was buried, and the nature of the sediment which covered it.† Not only do neighbouring veins show variations due to one or other of these causes, but even parts of the same vein may differ considerably. As an extreme case, the band of cannel which is associated with the No. 2 Rhondda Seam may be mentioned.*

† On these points reference should be made to the exhaustive researches on the origin of coal contained in the following works :—Grand 'Eury, F.C., 'Flore Carbonifère du Département de la Loire et du Centre de la France,' *Paris*, 1877. Fayol, H., and others, 'Etudes sur le terrain houiller du Commentry,' *Soc. de l'Industrie minérale, St. Etienne*, 1887–93. Renault, B., 'Sur quelques Micro-organismes des Combustible Fossiles,' *ib.* 1899–1900, and separately published. Barrois, C., 'Le Mode de Formation de la Houille,' *Ann. Soc. Géol. du Nord*, t. xxxiii., 1904. De Lapparent, A., 'Traité de Géologie,' Ed. 5, 1906, pp. 976–990. Potonié, H., 'Die Entstehung der Steinkohle,' *Berlin*, Ed. 4, 1907.

* 'The Country around Pontypridd and Maestêg' (*Mem. Geol. Survey*), 1903, p. 43, &c.

It is a fact, moreover, that most coals consist of laminæ of different appearance, the two kinds most commonly distinguished being dull coal and bright coal. Though it has not been shown, so far as we are aware, that any bituminous coal contains laminæ of true anthracite, it is certain that the dull and bright coal differ in the amount of bituminous matter they contain, the dull coal being described as "mineral charcoal."* The dull coal, moreover, can frequently be seen to be formed of fragmentary flattened stems, while the bright coal seldom shows organic structure. In all these variations between seams, and between parts or laminæ of the same seam, we see differences that can only be due to original deposition.

While, however, giving due weight to the evidence that the anthracitic character of the coals in part of South Wales is due to original conditions of deposition, we do not lose sight of the changes to which coals are liable in the process of time. It is a general rule that, other things being equal, coals associated with older formations approximate more closely to the anthracitic condition than those of later date. The rule is subject to many exceptions, for local circumstances, such as intrusion of igneous material, regional metamorphism, dislocation of strata, and the thickness and nature of the superimposed material, all produce some effect. The older the formation the greater is the chance of it having undergone one or other of these vicissitudes, while, apart from this, the lapse of time alone tends to effect changes in the character. So far as regards South Wales, it might be argued that the general rule that the older seams are the more anthracitic is due in part to one of these causes, namely, the fact that they were more deeply buried and exposed

* See analyses given in 'Coal, its History and Uses,' by Professors Green, Miall, Thorpe, Rücker, and Marshall. 8vo., London, 1878. To prove this point in a Welsh coal, a block of Three Quarter Coal from Monmouthshire was split along some dull layers, which presented a characteristic appearance. The dull material was scraped off and readily reduced to a powder not unlike charcoal. Another portion consisting wholly of bright coal was taken from the same block. The dull powder and the bright portion were then analysed with the following result :—

Proximate analysis of two samples of coal from the same block of the Three Quarter Vein.

	Bright Coal.	Dull charcoal-like Powder.
Moisture	1·75	1·68
Volatile matter	31·63	14·71
Fixed carbonaceous residue	63·96	77·17
Ash	2·66	6·44
Fuel-Ratio	2·02	5·24

to a higher temperature than the newer seams.* There is, however, no evidence that the coals in the synclines in South Wales are more anthracitic than those in the anticlines, though the difference in level sometimes amounts to several thousand feet. It would apparently be easy to over-estimate the effect due to this cause. Of all the suggested causes of alteration subsequent to deposition, none appear to have been adequate to produce more than a slight modification of the differences due to original composition.

* The same rule holds good in the coal-field of the Pas de Calais, where it is known as the *Loi de Hilt*. There it is attributed to metamorphism subsequent to deposition.

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Plate I.

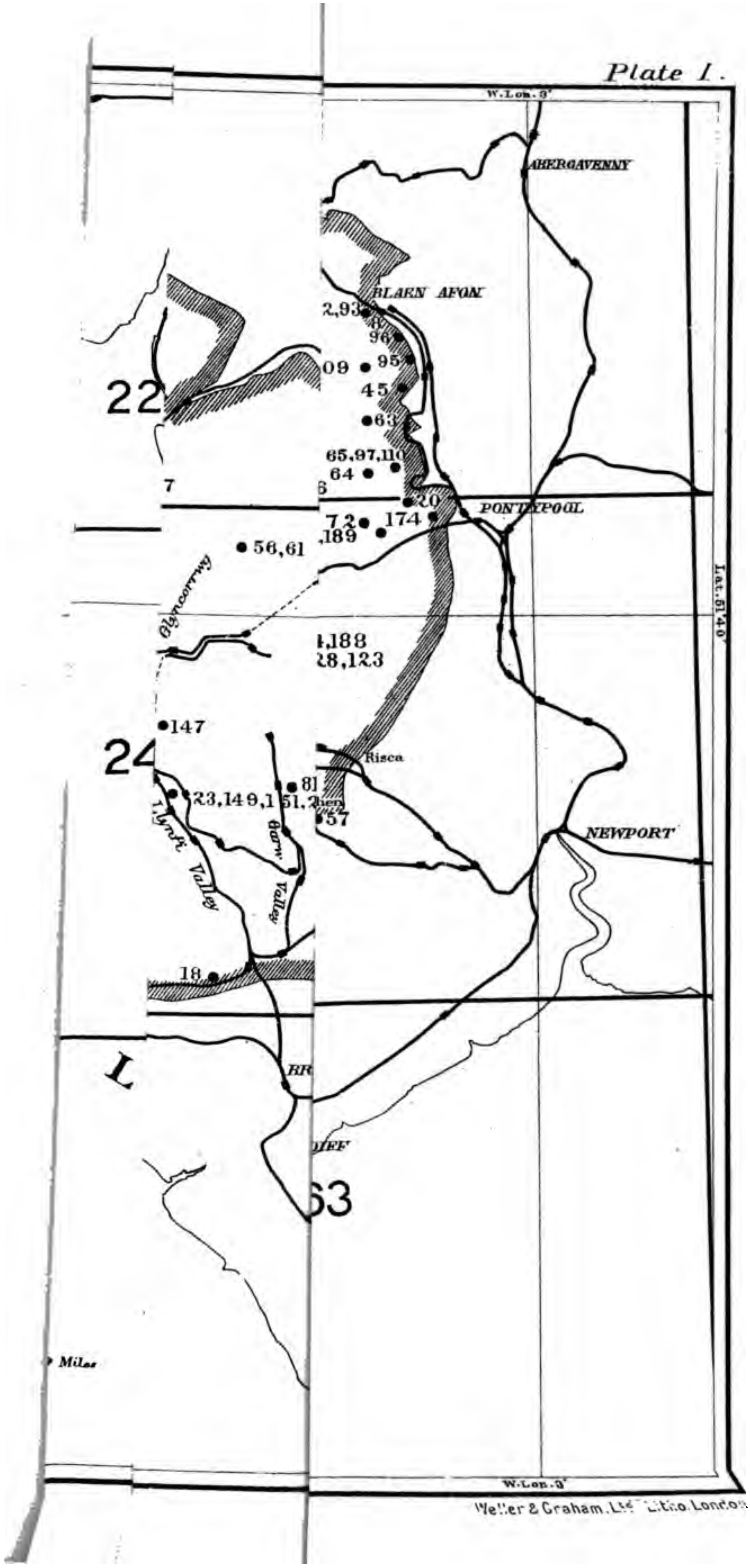

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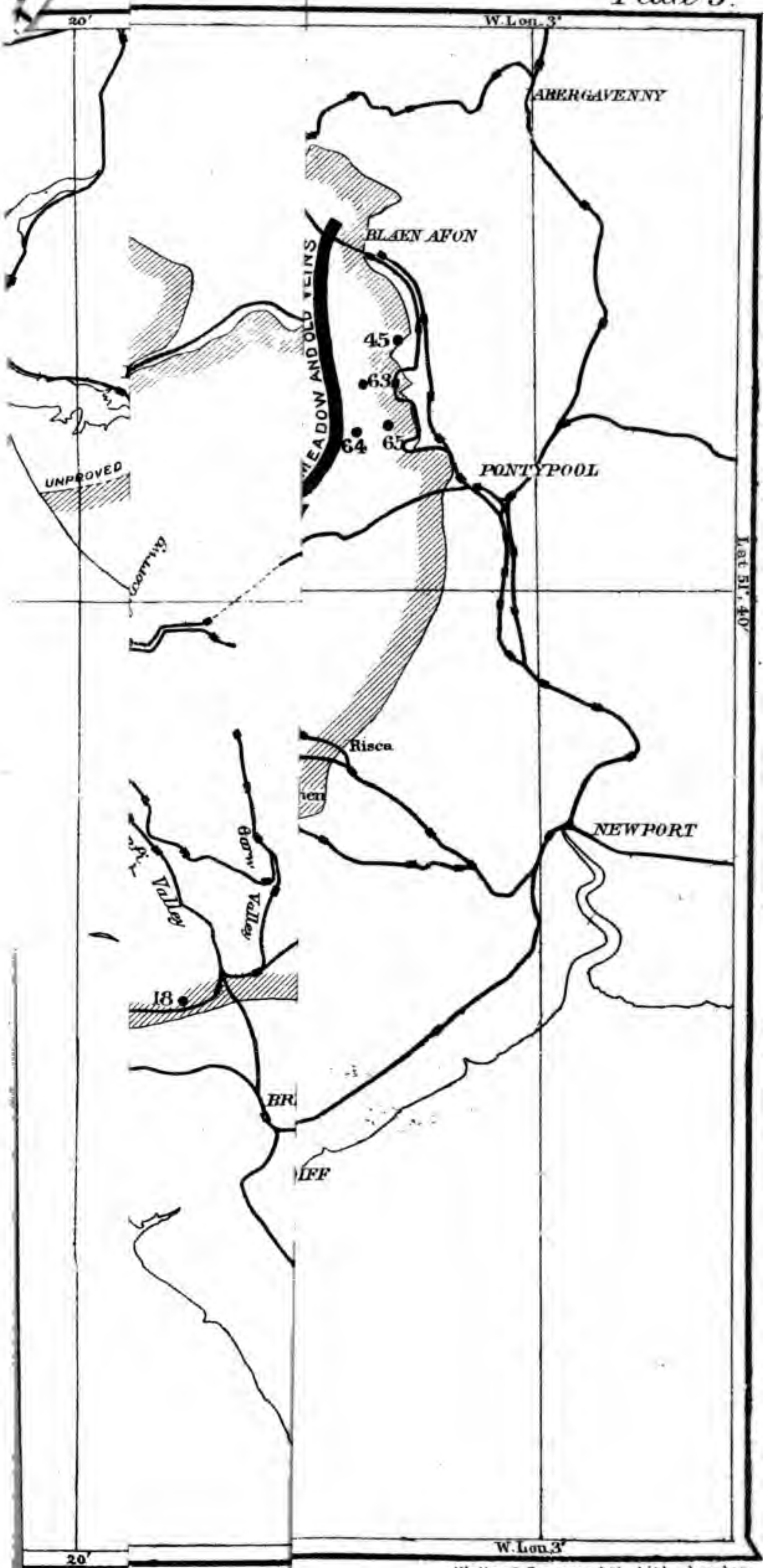
Plate 3.



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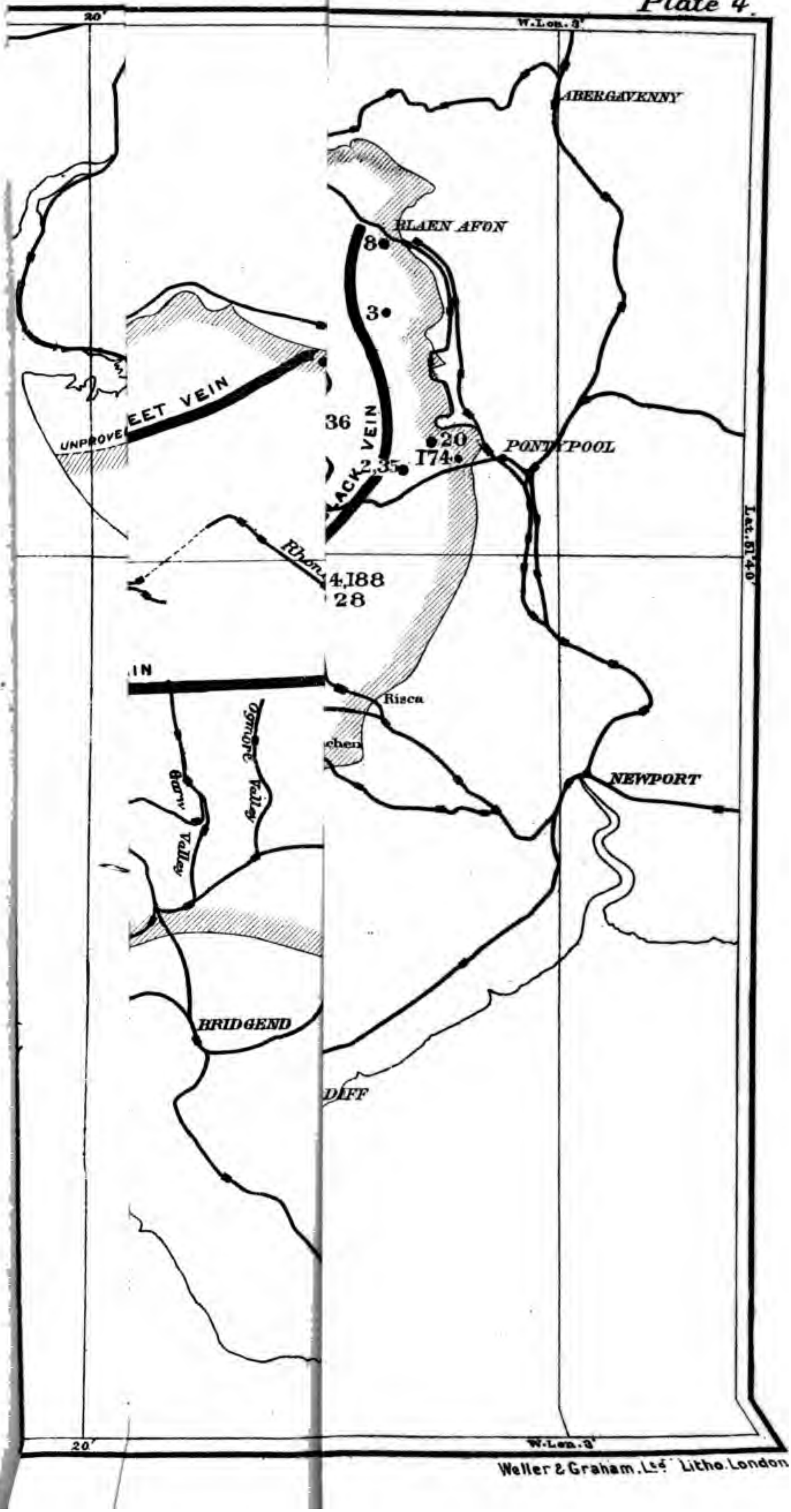

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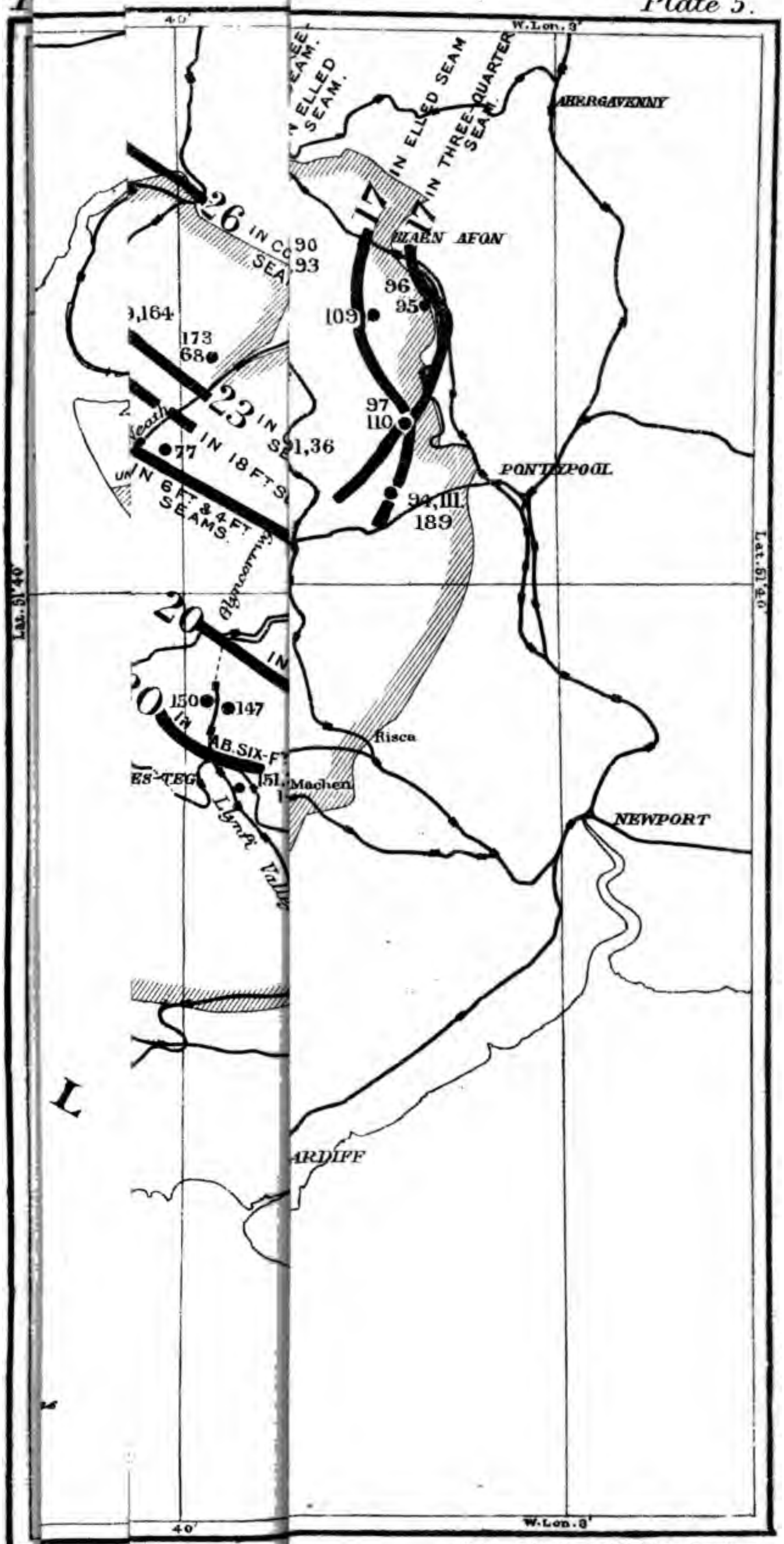

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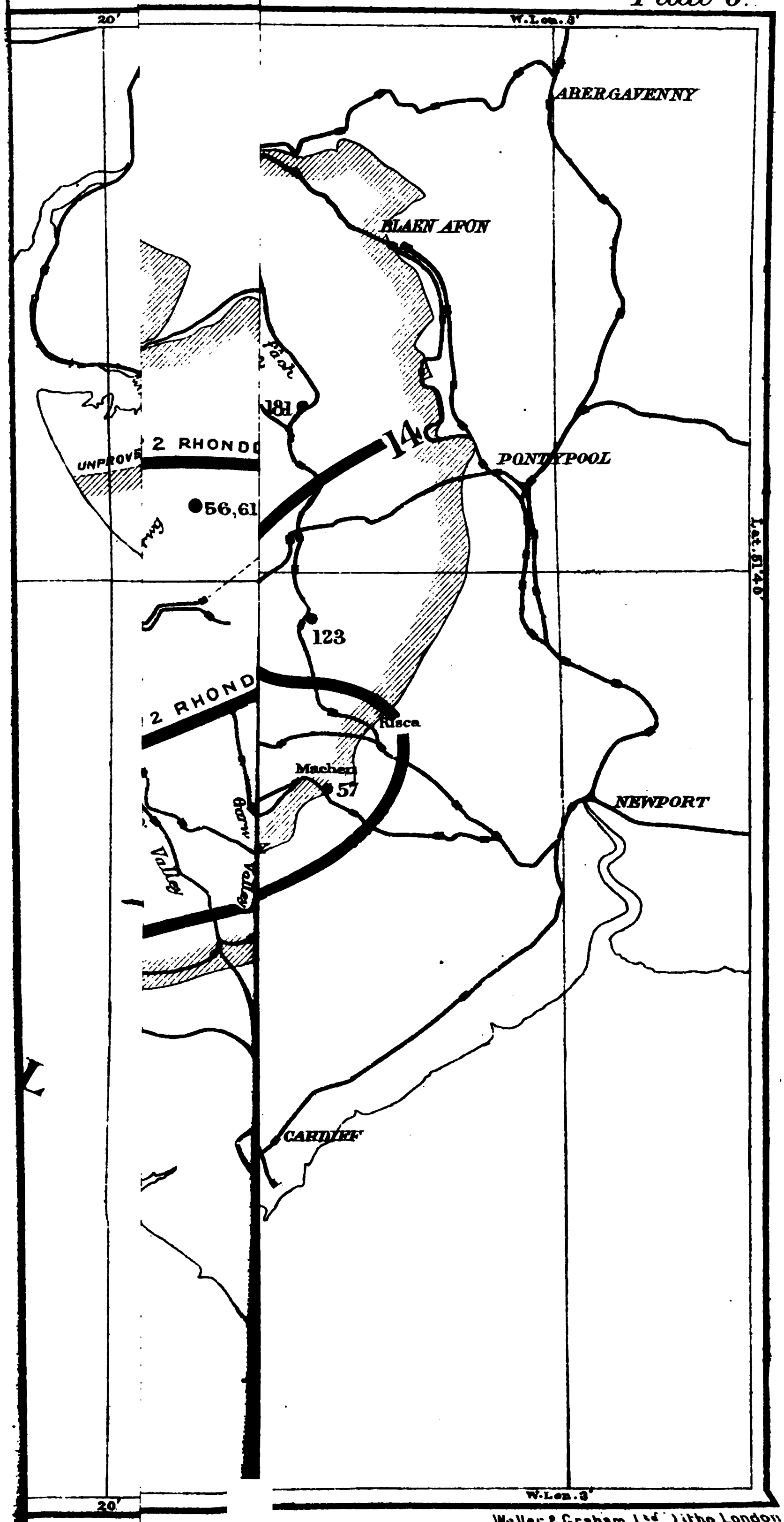

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Plate 7.

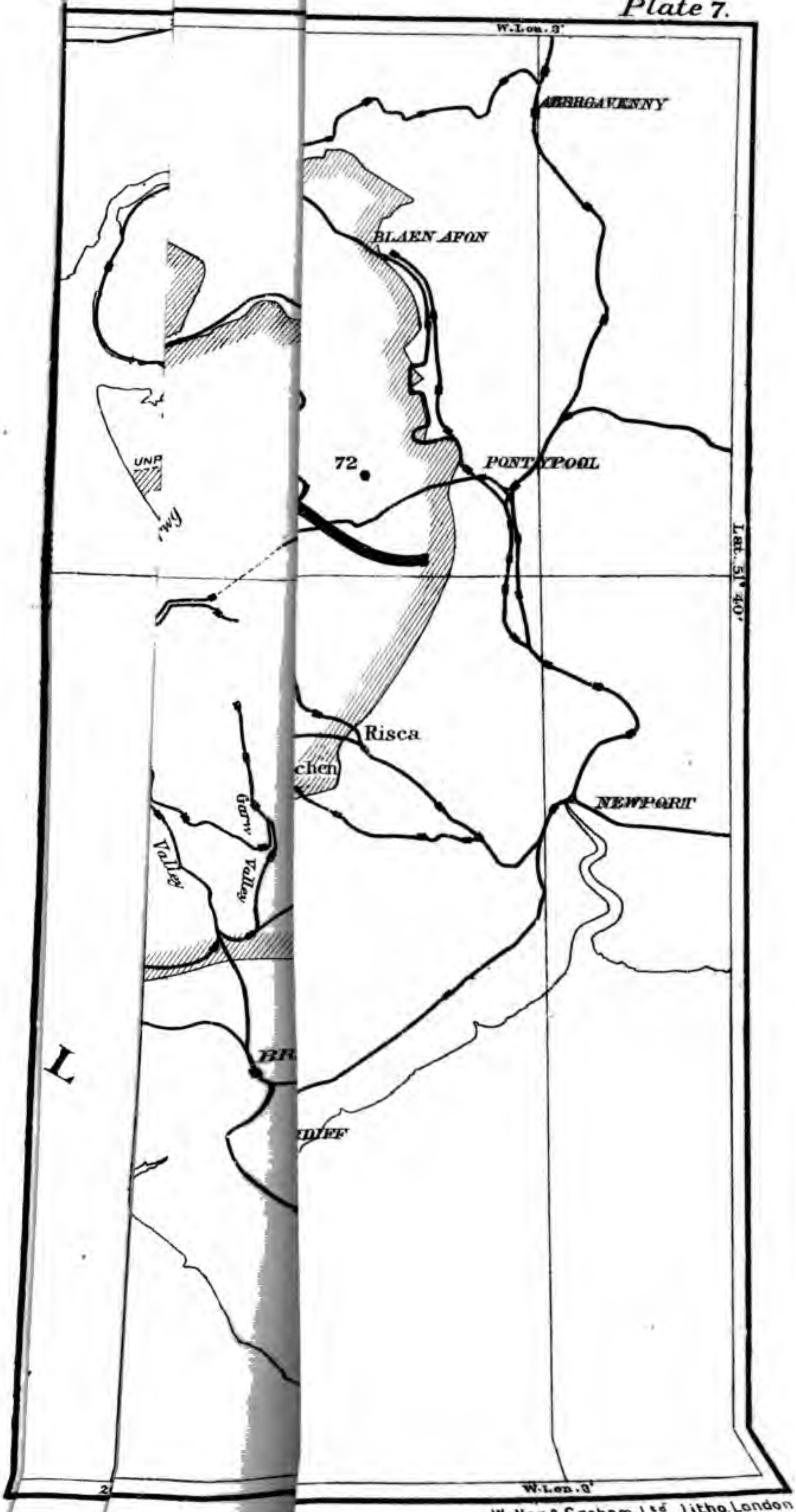

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Plate 8.

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POINTS OF OBSERVATION.

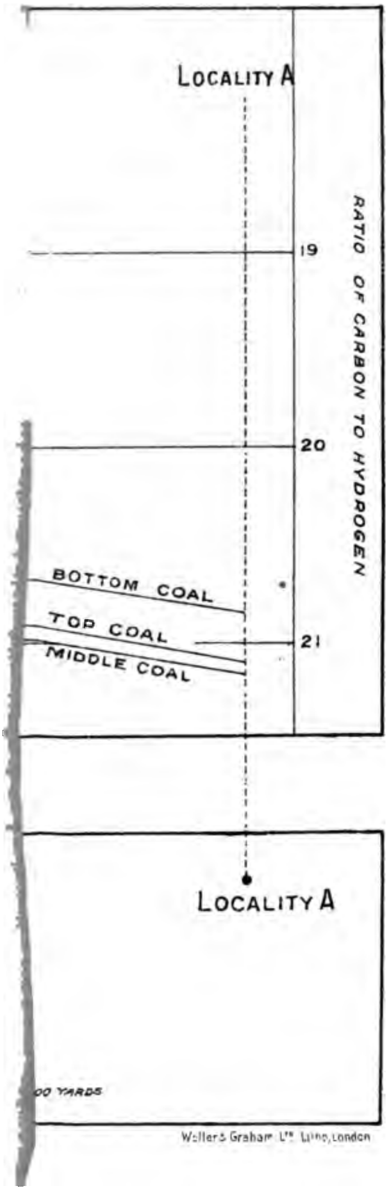

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Plate 9.

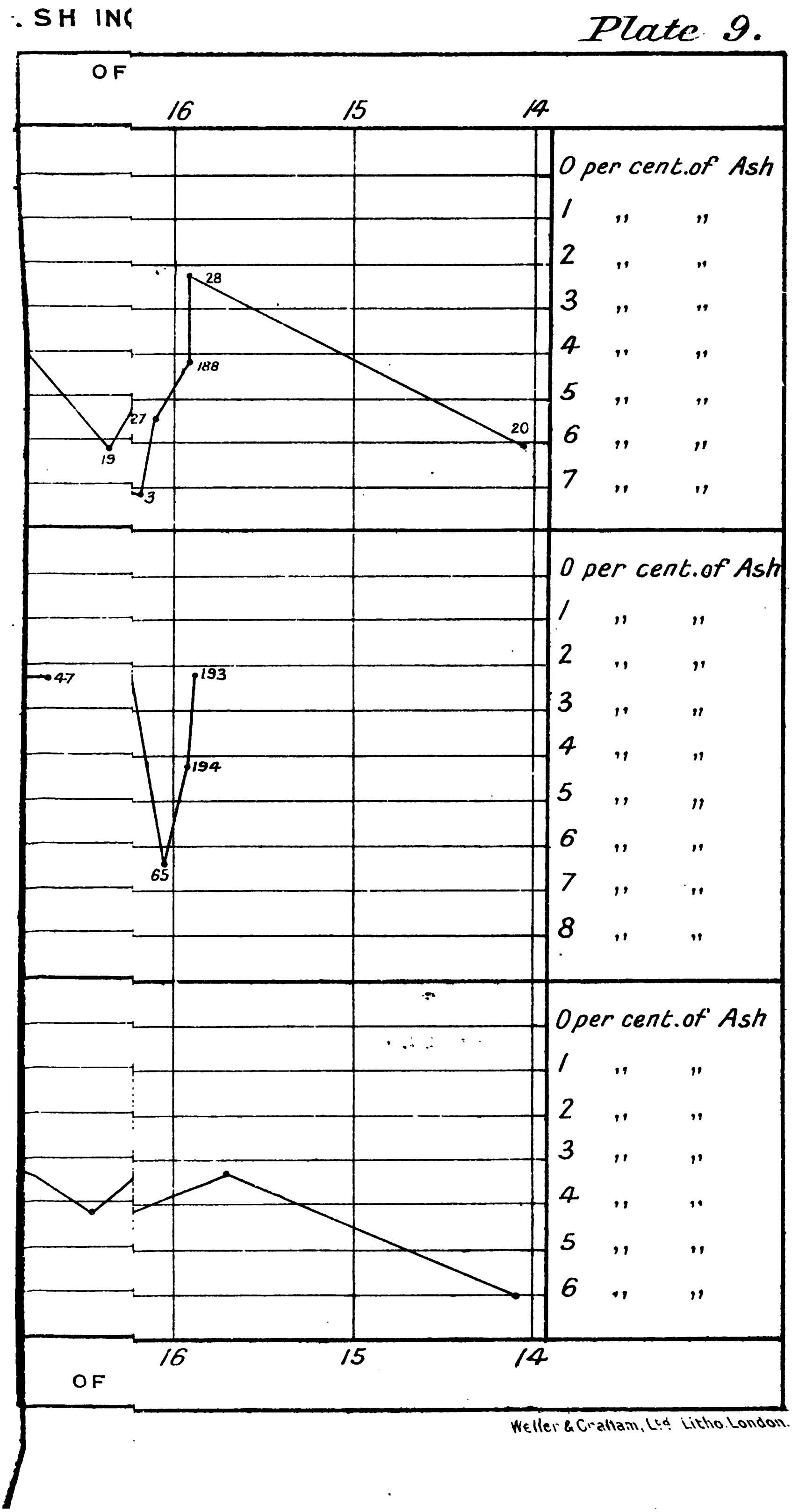

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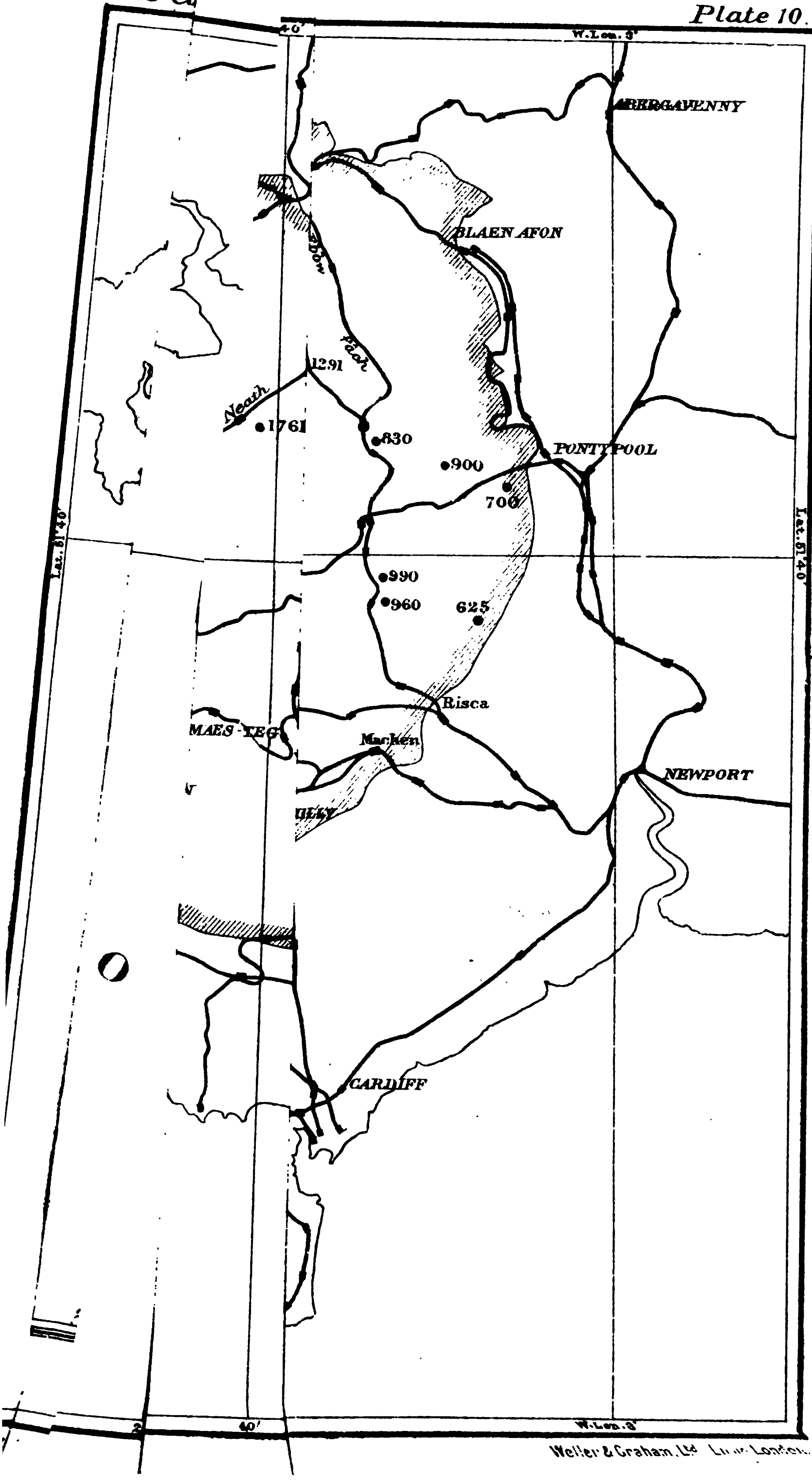
Plate 10.



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